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NASA CR-1405

STUDY OF THE ASTRONAUT'S CAPABILITIES TO MAINTAIN LIFE SUPPORT SYSTEMS AND CABIN HABITABILITY IN WEIGHTLESS CONDITIONS

by Harry L. Loats, Jr., George M. Hay, and Edwin Morris

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for Langley Research Center

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ENVIRONMENTAL RESEARCH ASSOCIATES
Randallstown, Md.

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By Harry L. Loats, Jr., George M. Hay, and Edwin Morris
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SUMMARY

The research conducted under contract NAS1-7887 comprised a study-simulation program to determine the major aspects of intra-vehicular tasks which are amenable to simulation by water immersion techniques. The main emphasis during the program was to determine the applicability of various restraint and locomotion aids related to the performance of a variety of critical intravehicular tasks. Although the exact nature of future space station missions and hardware is not fully defined at present, certain important characteristics are indicated.

The spectrum of functional and experimental requirements which generated the tasks simulated were derived from various existing NASA space station configuration studies. Four representative IVA task categories were investigated. These included General and Housekeeping, Equipment Operation, Cargo Handling, and Maintenance tasks.

In the General and Housekeeping area a representative duty cycle of the astronaut crewman was simulated including space suit and constant wear garment don and doffing, food preparation, resting, personal hygiene, and exercise tasks. All other task simulations were designed to specifically investigate certain portions of representative or existing prototype space hardware.

Specific locomotion aids investigated during the contract included: handrails around the compartment perimeter, portable type handrail specifically located proximally to critical hardware components, handrail-walking combinations, pressure walking between surfaces, soaring, fixed handholds, and velcro sandals. The restraints evaluated during the simulation included: fixed chair and seat belt, positive foot restraints of the Gemini type, toe traps, handholds, multiple and single waist tethers, handrails located around the compartment periphery, and velcro sandals.

Specific characteristics of the tasks were investigated and included: maintenance and repair of life support systems; working at a work bench, a standup platform, a work station, and a control

console; locomotion about the interior of the compartment, data collection tasks including writing and calculations, cargo handling and storage, and general and housekeeping tasks. Prior to the simulation effort a literature survey and study was made to ascertain the current status of the knowledge and experimental data relative to the simulation and performance of IVA tasks.

INTRODUCTION

Forthcoming space missions, wherein full scale manned intravehicular (IVA) operations will be utilized, are currently assuming greater importance. In both the Gemini and the Apollo spacecraft the limited size of the crew quarters precluded extensive IVA operations. Much information has been forthcoming from the Gemini program however, on the capability for manned operation while seated inside a spacecraft of limited volume during weightlessness. This information, coupled with the extensive research and operational experience related to Gemini EVA, forms the basis for the present study of the effectiveness of restraints and motion aids during IVA task simulation by water immersion techniques.

The present program entails a study effort to determine the major aspects of the IVA tasks which are amenable to simulation by water immersion techniques, the postulation and development of adequate techniques for the simulation, and the performance of a fifteen man-month simulation program; including the simulation plan, the fabrication of hardware, the simulation performance, data analysis and report which relates specific representative tasks to various restraint and locomotion aid hardware established by the NASA and the contractor.

Various sources of information were used in the study phase to derive a representative system configuration and task baseline. These included, primarily, data from the Gemini mission as well as from various recognized NASA space station design studies. The major emphasis of this study was to arrive at composite intravehicular tasks which represent technology requirements necessary for the support of long duration space station missions. The tasks were designed to emphasize not only primary requisite technology, but also to encompass future systems wherein the in situ astronaut-experimenter would begin to exercise a major role in the proposed experimental program.

ESTABLISHMENT OF REPRESENTATIVE IVA TASKS

In the immediate future, astronauts and astronaut-scientists will be called upon to operate for relatively long durations inside orbiting space stations. They will be required to routinely perform in a weightless or low gravity environment many of the tasks that they currently perform at normal earth gravity. The experience which they can bring to bear cannot, however, be directly translated from its earth-bound counterpart. Many critical elements of hardware disign and man-machine inter-relationships governing hardware utilization must be researched, evaluated and specified. This is particularly true since man-hour utilization aboard spacecraft has been identified by many researches as the most critical resource.

The Gemini program has shown us that man can perform many useful and important functions aboard orbiting spacecraft in a manner relatively similar to that of normal one gravity operation. The compatibility and efficiency of two men crews operating in close quarters has been demonstrated for periods up to fourteen days. The astronauts have successfully implemented a relatively complex operational and experimental program including:

- Onboard calculation, control, monitoring, and evaluation of rendezvous techniques.
- Functional performance of photographic data gathering for many and various scientific disciplines.
- The ability to act as a visual data link in the operation of systems and equipment.
- The ability to exercise immediate control over the system, to exercise direct decision-making capability and to effect proper corrective action.
- Functional performance of many and various types of onboard experiments gathered from the several scientific and technical disciplines.
- Adequate accommodation to the housekeeping aspects of living and working in space.

Table I (ref.1) presents a synthesis of the results of the Gemini programs related to current estimates of man's response to operation in space.

Estimate of Space and Volume Allocation

As crew size and mission duration increase, it becomes imperative that a proper determination of spatial and volume allocation be made. While it is obvious that the precise determination of space and volume requires an exact knowledge of the system configuration,

the time is now right to undertake analytical and experimental programs designed to obtain the pertinent information. Certain data exists which can be drawn upon as a baseline of information. These include data from the Mercury and Gemini missions and data from scientific missions such as polar expeditions, mountain climbing, and data from such closely related fields as submarine operations, etc.

The specification of minimum volume and space allocation for small to intermediate crews over prolonged periods is presently beyond the state-of-the-art. However, certain guidelines have been developed.

- Living quarters should be distinct from work quarters.
- The better the specification of functionally separate, habitability-engineered compartments, the greater the compatibility of the crew.
- In general, future astronauts, albeit not necessarily flying personnel, will be selected as regards standard aircrew personnel selection criteria.

Figure 1 (ref. 2) shows the available data concerning volume allocation drawn from pertinent aerospace and military sources. The figure also includes the projected volume allocation per man from the summary report - Preliminary Technical Data for Earth Orbiting Space Stations.

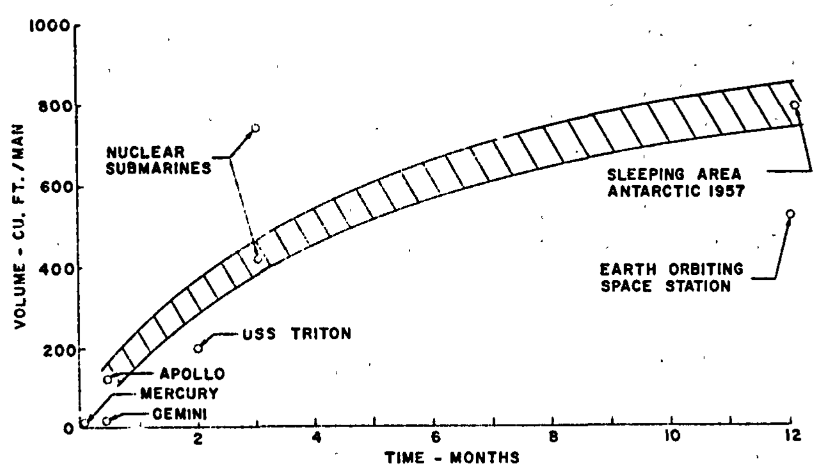


FIGURE 1 - TOTAL HABITABLE LIVING VOLUME (ref. 2)

TABLE I * HUMAN RESPONSE TO SPACEFLIGHT

PREDICTED	OBSERVED
DYSBARISM	NONE
DISRUPTION OF CIRCADIAN RHYTHM	NONE
DECREASED G TOLERANCE	NONE
SKIN INFECTION AND BREAKDOWN	DRYNESS, INCLUDING DANDRUFF
SLEEPINESS AND SLEEPLESSNESS	MINOR INTERFERENCE
REDUCED VISUAL ACUITY	NONE (EYE IRRITATION)
DISORIENTATION AND MOTION SICKNESS	NONE
PULMONARY ACETECTASIS	NONE
HIGH HEART RATES	LAUNCH, REENTRY, EVA
CARDIAC ARRHYTHMIAS	NONE
HIGH, LOW BLOOD PRESSURE	NONE
FAINTING POSTFLIGHT	NONE
EM DELAY IN CARDIAC FUNCTION	NONE
REDUCED CARDIOVASCULAR RESPONSE TO EXERCISE	NONE(ABSOLUTE NEUTROPHILIA)
REDUCED BLOOD VOLUME	NONE
REDUCED PLASMA VOLUME	MINIMAL
DEHYDRATION	MINIMAL
WEIGHT LOSS	VARIABLE
BONE DEMINERALIZATION	MINIMAL CALCIUM LOSS
LOSS OF APPETITE	VARYING CALORIC INTAKE
NAUSEA	NONE
MUSCULAR INCOORDINATION	NONE
MUSCULAR ATROPHY	NONE
IMPAIRED PSYCHOMOTOR PERFORMANCE	NONE
SEDATIVE NEED	NONE
STIMULANT NEED	OCCASIONALLY BEFORE REENTRY
INFECTIOUS DISEASE	NONE
FATIGUE	MINIMAL

* ref. 1

Figures 2 and 3 (ref. 2), also drawn from this study, depict the volume and spatial requirements as a function of time in space. For the present study, we have chosen to fall within the boundaries of this framework. A module area of approximately 36 sq ft with a height of 7 feet was selected to be representative of the various work and personnel crew areas

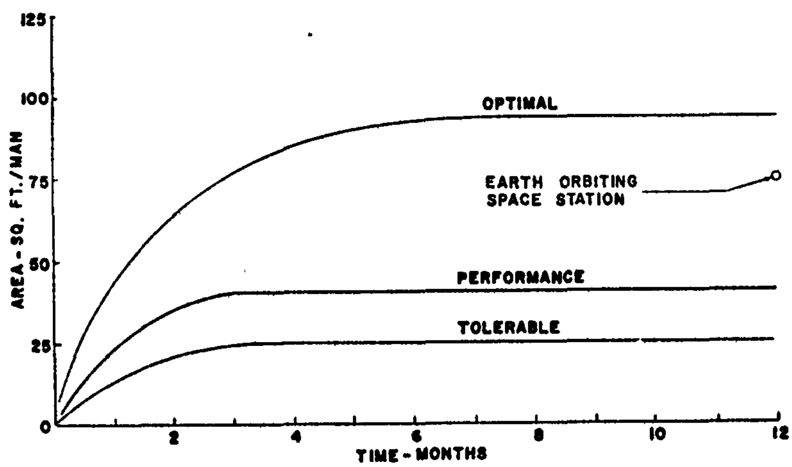


FIGURE 2 - LIVING SPACE PER MAN (AREA) (ref. 2)

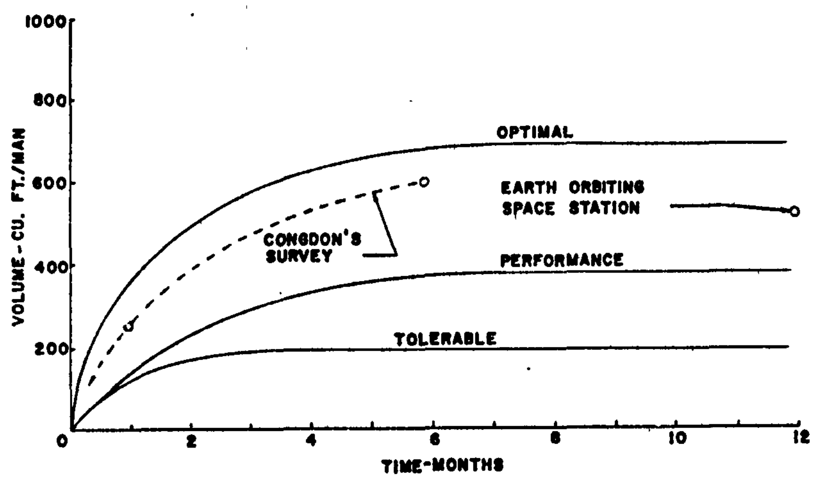


FIGURE 3 - LIVING SPACE PER MAN (VOLUME) (ref. 2)

Determination of Representative Tasks

The exact character and nature of future space missions is not fully defined at present. Dertain important characteristics, however, are indicated. There will probably be a period of space experimentation wherein maximum utilization of extended life workshops will form the core of the space program. Gradually phasing into the program after that period will be the one and one half and two year space station concepts. The space stations will be primarily involved with scientific applications.

The spectrum of experimental requirements were derived from the experiments proposed for such configurations as MORL, ORL, and AES. These experiment lists are constantly being amended, updated, and refined and have resulted in a fluid experiment program. Along with these experiments, there are also certain other hardware concepts such as the GEP and the MOT which have at least reached the research phase. It is from these experiment lists and system preliminary designs that the following representative IVA task categories wer chosen. These categories, General and Housekeeping, Equipment Operation, Cargo Hangling, and Maintenance, shown in Figure 4, form the baseline for the simulation phase of this contract. Each category was expanded by detailing a representative system configuration, specifying IVA personnel hardware and tasks, and determining specific restraint and locomotion aid configurations to be utilized during the performance of each task.

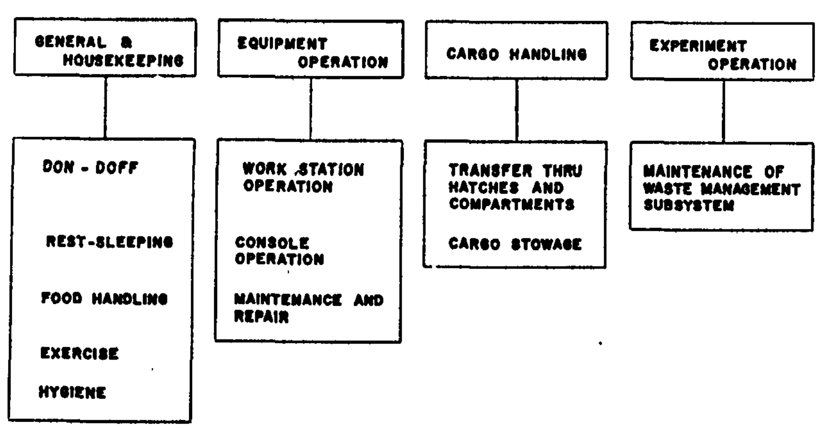


FIGURE 4 - IVA TASK CATEGORIES

Table II shows the relationship of the four task categories to the restraint and locomotion aid candidates.

The four categories were chosen as particularly representative of future IVA task requirements. For example, the Cargo Handling task involves the transfer of representative gas cylinders and the mating of these cylinders to a manifold located in the experiment bay. Particular attention was given to determining the critical aspects of this task, e.g., space allocation employing a variable dimension storage area and the effectiveness and utility of an erectable motion-transfer aid. In the Equipment Operation category, a configuration utilizing NASA-LRC supplied equipment to represent a guidance and navigation station specifically evaluated seated versus standing operation and also investigated the data collection aspects of IVA tasks. Table III shows the relationship of maneuver requirements to the simulation task categories.

In the General and Housekeeping area, a representative duty cycle of the astronaut crewman was simulated including space suit and constant wear garment don and doffing, food preparation, resting, personal hygiene and exercise. These tasks were performed in a serial manner in order to increase the data yield.

The final category, Experiment Operation, was designed to investigate a representative experimental task requiring critical IVA astronaut operation and comprised the operation of a Maintenance and Repair task which closely represents NASA-LRC interest in the in-orbit experiment operation area.

Status of Present Knowledge

Having identified the four areas to be investigated during the simulation phase of this contract, a literature survey was undertaken to assess the current status of background knowledge directly related to these areas. In general, the research performed was mostly based on prospective design concepts like AORL, MORL, AES, and MOL. A great deal of peripheral information was utilized from studies performed by the USAF on standard human factors design criteria for aircrew personnel, from similar studies done by the USN, and also by many supporting efforts by the technical community.

The NASA has supported an effort by Webb Associates to compile much of this information. The results of this study are given in the NASA Life Sciences Data Handbook (ref. 3) particularly in the chapters entitled--Energy and Size and Motion. This was supplemented by the data supplied in USDHEW report--Weight, Height and Selected Body Dimensions of Adults (ref.4) which specified descriptive and standardized measurement techniques. A thorough description of the major effects of weightlessness on IVA operations was given by Simons in his Description of Surface Free Behavior (ref.5) which summarized his researches and experience in the zero gravity

TABLE II

RELATIONSHIP OF THE TASK CATEGORIES TO THE CANDIDATE RESTRAINT AND LOCOMOTION AIDS

LOCOMOTION AIDS	TASK			
	GENERAL AND HOUSEKEEPING	EQUIPMENT OPERATION	CARGO HANDLING	MAINTENANCE
HANDRAILS AROUND STATION PERIMETER	-	X	X	X
HANDRAILS (PORTABLE TYPE)	-	-	X	-
HANDRAILS-WALKING COMBINATIONS	-	X	X	X
PRESSURE WALKING BETWEEN SURFACES	-	-	X	-
SOARING	-	-	X	X
HANDHOLDS	X	X	X	X
VELCRO SANDALS	X	X	X	X
RESTRAINTS				
CHAIR AND SEAT BELT	-	X	X	X
POSITIVE FOOT RESTRAINTS	X	X	X	X
TOE TRAPS	-	X	X	X
HANDHOLDS	X	X	X	X
WAIST TETHERS (2)	X	X	X	X
SINGLE FLEXIBLE STRAP	X	X	X	X
HANDRAILS AROUND STATION	-	X	X	X
VELCRO SANDALS	X	X	X	X

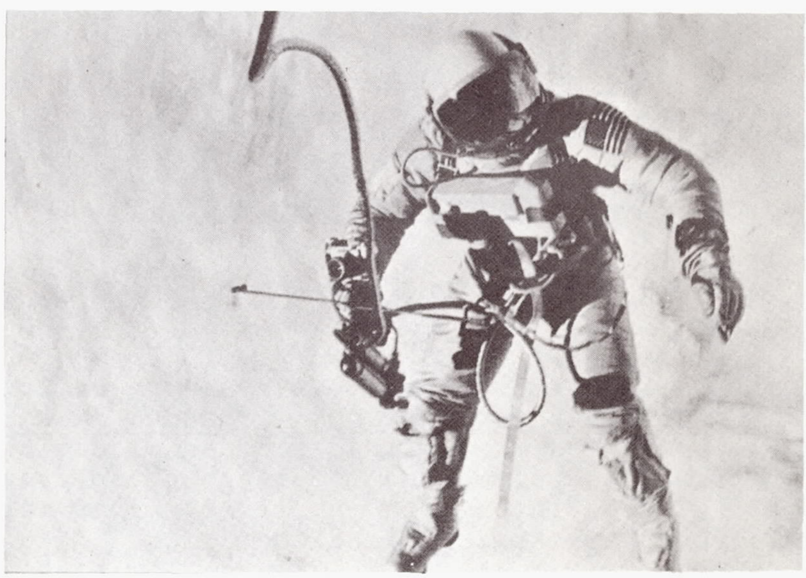
TABLE III

RELATIONSHIP OF MANEUVERS TO THE SIMULATION TASK CATEGORIES

MANEUVERS	TASKS			
	GENERAL AND HOUSEKEEPING	EXPERIMENT OPERATION	CARGO HANDLING	MAINTENANCE
MAINTENANCE AND REPAIR OF LIFE SUPPORT SYSTEM	-	X	X	X
WORKING AT WORK BENCH, PLATFORM, WORK STATION	X	X	X	X
WORKING AT CONTROL CONSOLE	-	X	-	-
LOCOMOTION ABOUT INTERIOR OF SPACECRAFT	X	X	X	X
DESK WORK, WRITING AND CALCULATIONS	-	X	-	-
MANEUVERING AND TRANSLATION	X	X	X	X
CARGO HANDLING AND STORAGE	X	X	X	-
HOUSEKEEPING	X	-	-	-
PHYSICAL CONDITIONING AND EQUIPMENT USE	X	-	-	-
FOOD PREPARATION AND EATING MODES	X	-	-	-
PERSONAL HYGIENE	X	-	-	-
REST MODES AND EQUIPMENT USE	X	-	-	-
SLEEPING MODES AND EQUIPMENT USE	X	-	-	-
DRESSING	X	-	-	-
PRESSURE SUIT DONNING AND DOFFING	X	-	-	-
EXPERIMENT PERFORMANCE	X	X	-	X

research aircraft. His studies included free soaring, locomotion employing various motion aids such as magnetic shoes and velcro attachments, and the ability to exert torque and push-pull forces while unrestrained. Simons, et.all., made an interesting observation of the relaxed posture of personnel free-floating in the zero gravity aircraft. From information gathered from personnel comment, it was concluded that Figure 5 represents an optimum posture for resting in zero gravity environments.

WATER IMMERSION SIMULATION



GEMINI IN ORBIT

FIGURE 5 - OPTIMUM RESTING POSTURE IN ZERO GRAVITY

The USAF has also published a series of research reports on the reach capability of the USAF population. The purpose of the reports was to describe the outer boundaries of the minimum, 5th, 50th, and the 95th percentile grasp-reach envelopes for shirt-sleeved, seated operators. The work also offers a detailed discussion related to the factors influencing reach capability. ERA has performed similar work using the water immersion technique. Figure 6 shows an ERA subject performing a reach measurement task in a full pressure suit.

FIGURE 6 - SUBJECT PERFORMING REACH MEASUREMENT TASK

Kennedy, et.al., also performed similar research on Aperture Sizes and Depths of Reach for One and Two Handed Tasks (ref. 6). In this work he presented the optimal size and location of maintenance apertures and supplemented the reach-grasp data to include working reach distances through the aperture. This work included both shirt sleeve and pressure-suited operation. A typical result is given in Table IV. (ref. 6) Similar data for standing subjects and subjects seated on conventional chair arrangements were also given.

Space suit donning and doffing has been the subject of considerable simulation effort both at ERA and at various governmental facilities. ERA has performed space suit donning using the Navy Mark IV Mod 0 suit in the water immersion mode. This donning and

doffing has been performed both without spatial constraints and internal to the proposed ALM structure. The results in all cases have shown that space suit donning is feasible but (1) the time required for the donning operation greatly exceeds the time required in one gravity environment, (2) that the dimensional restrictions accruing to donning in the ALM did not appreciably change the time or mode of donning over execution in unrestrained space, and (3) that the donning and doffing procedure could materially benefit from the use of external body positioning restraints to stabilize the subject and the suit during the operation.

TABLE IV MOBILITY ENVELOP (ref. 6)

PERCENT OF WEIGHTED MOBILITY POINTS COMPARED WITH CURRENT SUIT TECHNOLOGY. BEST SUIT = 100 PERCENT			
	SUIT A	SUIT B	SUIT C
VENTED	67	52	95
PRESSURIZED	77	68	72
PERCENT OF WEIGHTED MOBILITY POINTS COMPARED WITH NUDE RANGE. NO RESTRICTION = 100 PERCENT			
VENTED	63	53	82
PRESSURIZED	62	57	58

NASA has tentatively specified space (22.75 cu ft) which has the approximate shape of a cylinder 26 inches in diameter by 72 inches high for the Apollo astronaut to don and doff his suit. Sasaki (ref. 7) has reported that the mean donning time was 167 seconds and the mean doffing time was 95 seconds. Mean don-doff times in the water immersion mode were approximately 1,800 seconds. The apparent reasons for the large discrepancy between donning-doffing in the water immersion and the zero gravity aircraft simulation mode are (1) the difference between the suits used and (2) the hindrance caused by the action of the water.

Some questions have arisen as to the effect of breaking the task into 30 second increments which is required by the operation of the zero gravity research aircraft. This stoppage may tend to eliminate unwarranted subject action since every 30 seconds the task is restaged from a new position in the time line.

The work on walking in a zero gravity environment was pioneered in 1959 by the USAF in the work of Simons and Sharp (ref. 8) who

studied the ability of a subject to walk with the aid of velcro boots and magnetic sandals. Results of the walking experiments with the aid of velcro on the shoes showed that the holding power was limited due to the limited area of contact between the male and female velcro. The overall results showed that the utility of velcro as an aid to walking is limited, seriously affecting both the mode of walking and body position during walking. Evaluation of the magnetic shoe concept was not fully successful due to artifices induced by the zero gravity aircraft. It was found that a magnetic attractive force of approximately 20-22 pounds was required to hold a 190 pound walking subject. Gross orientation and pendulum effects were also noted. It was concluded that walking with magnetic shoes significantly altered normal walking patterns. There is no report of further work in this area.

Closely related to the subject of walking in zero gravity is the utility of other forms of locomotion. For example, the Gemini program albeit mainly concerned with EVA offers considerable insight to the problems of IVA locomotion. Table V summarizes the use of restraint and locomotion aids on the Gemini program. Most of the restraints and locomotion aids listed were subjected to a substantial amount of water immersion simulation. The utility of these motion aids and restraints was acknowledged by most of the EVA pilots and was confirmed by study which dealt specifically with the comparison of the results from space to those of the water simulation. ERA has, in parallel underwater simulation, evaluated certain of these restraints and locomotion aids in non-pressure-suited applications. The information from these research-simulation efforts forms the baseline for the subsequent IVA simulation.

The results of the Gemini EVA showed that the restraints and locomotion aids found most satisfactory were: (1) Gemini XII foot restraints (rest and localized work), (2) Gemini XII waist tethers (rest and localized work), (3) rectangular handrail for translation across surfaces, and (4) pip-pin devices for localized attachments.

The foregoing subjects, for the most part, represent basic areas of research which are combined in various ways to yield the data required for the design specification of displays and controls, work and personnel spatial allocations, optimum configurations for use of auxiliary equipment, and for such specific tasks as material handling, transfer, and stowage.

The material handling problem in a weightless environment was summarized by workers at the University of Dayton Research Institute in UD memorandum 150 (ref. 9). In this report, several rules of operation were proposed: (1) a man must either have external power or a method of anchoring to effectively maneuver an object in space, (2) there is no theoretical limit to the size, shape, or configuration of the object to be handled, (3) the time and energy

relationships for material transfer tasks can be determined and follow an inverse relationship, and (4) the center of gravity of the object should be clearly marked in order to facilitate handling.

TABLE V

LOCOMOTION AIDS AND RESTRAINTS USED DURING GEMINI EVA

DEVICE	GEMINI MISSION			
	9-A	10	11	12
RECTANGULAR HANDRAIL	X	X	X	X
LARGE CYLINDRICAL HANDRAIL (1.36"ϕ)	X	-	-	X
SMALL CYLINDRICAL HANDRAIL (0.317"ϕ)	-	-	-	X
TELESCOPING HANDRAIL	-	-	-	X
FIXED HANDHOLD	-	-	X	X
RIGID VELCRO-BACKED PORTABLE HANDHOLD	-	-	-	X
FLEXIBLE VELCRO-BACKED PORTABLE HANDHOLD	X	-	-	-
WAIST TETHERS	-	-	-	X
PIP-PIN HANDHOLD/TETHER ATTACH DEVICE	-	-	-	X
PIP-PIN ANTIROTATION DEVICE	-	-	-	X
U-BOLT HANDHOLD/TETHER ATTACH DEVICE	-	-	-	X
FOOT RESTRAINTS	X	-	-	X
STANDUP TETHER	-	X	X	X
STRAPS ON SPACE SUIT LEG	-	-	X	X

NASA (ref.10) has conducted research on material handling and transfer in the water immersion mode but the results of the study were inconclusive due to the limited task replications performed. Material handling and transfer is particularly complicated in the water immersion mode by drag and planing effects induced by motion of the package through the water. Methods have been proposed for overcoming this problem which comprise the detailed scaling of hydrodynamic effects. Practical results of this approach were not, however, reported. These techniques may, however, offer a solution to the problems of handling and transferring packages simulated by water immersion techniques.

The USAF and USN are continuously involved in studies intended to develop generalized and specific data on displays, controls, and space allotments. The basic design criteria is carefully covered by Ely, Thomson, and Orlansky (ref. 11). The report is divided into four main parts: general consideration, workplace dimension, location of controls and displays, and direction-of-movement relationships. Specific tables and figures relate to optimum and maximum viewing area, manual areas, pedal areas, comparisons of seated and standing positions, general workplace dimensions, grouping of controls and displays, and direction-of-movement for controls for both seating and standing conditions.

In summary, much work has been done by Government and private research groups which forms a closely related baseline for the present study-simulation. Maximum use was made of this data for comparison purposes and to indicate areas where simulation seemed particularly applicable or inapplicable.

IVA SIMULATION PROGRAM

General Characteristics

Heretofore, meaningful experimental research on nonpressure-suited IVA tasks has been generally restricted to support of simulated pressure-suited extravehicular tasks. ERA has performed IVA support tasks both for its contracts NAS1-4059, Ingress-Egress Thru Passageways and Air Locks (ref. 12) and for the ALM tasks in NAS9-6584. Concommitantly, nonpressure-suited runs of the majority of tasks simulated in water immersion by ERA have also been accomplished for equipment checkout purposes.

To accomplish research on nonpressure-suited IVA tasks, an operational technique is required wherein subjects wearing clothing representative of IVA dress must be maintained at near neutral buoyancy. The excess buoyancy of the pressure suit cannot be depended on to permit additional ballast to be added, thus bringing the subject to neutral buoyancy. The following technique was initiated and perfected during the program.

The possibility that conventional SCUBA and HOOKAH apparatus may degrade the performance of certain IVA tasks warranted a new approach to the underwater simulation life support system. Preliminary investigation by ERA personnel indicated that both the primary life support system and the ancillary environmental correction devices must be modified to attain a more accurate simulation.

The air supply and exhaust have been handled in the past through a bulky umbilical or self-contained system. For the pressure-suited EVA requirements and for a limited number of mixed IVA-EVA, such as package transfer through air locks, these systems are acceptable

and technically correct. The majority of IVA tasks are, however, accomplished in a shirt sleeve environment. The personnel life support systems necessary for simulated EVA would not be acceptable for IVA task operation. Underwater simulation of IVA requires the separation of the subject and his air supply. To accomplish this separation, an air demand and exhaust system was placed at appropriate positions in the IVA mock-up.

The major design requirement was for a system for proper ballasting and dress techniques providing minimum volume increase. An IVA water immersion simulation technique was developed during the first part of the contract phase and the appropriate combination of equipment was used during the remainder of the contract.

The following describes the configuration of the system for the simulation phase of the contract. The subject wore a conventional SCUBA wet suit overcovered by a standard version Air Force flight suit. The shoes comprised wet suit slippers modified to include velcro material. Weights were attached where appropriate to provide mean neutral buoyancy, e.g., the net buoyancy was adjusted to the mean between full exhale and full inhale conditions of the particular subject. The subject obtained air from HOOKAH ports strategically located on the neutral buoyancy simulator. The rate of air intake was maintained sufficient to produce a smooth task flow. In the event that the subject required air during a subtask performance, such that he was required to return to a "HOOKAH" port, this time was noted and subtracted from the overall performance time. The optimum location for the fixed or semi-fixed air intake ports was determined as a result of the initial performance runs for each task.

The mock-ups were submersed in approximately an 11 foot water depth and camera locations were determined to provide necessary photographic data coverage. Specific variations of the equipment and mock-up configurations are covered under the description of the individual tasks.

Data from the water simulation was established by a time and motion evaluation of each task. The example below illustrates the format employed. Each subtask element is first related to its appropriate task and subtask. The subtask element is described and the time of performance is determined from direct observation and film analysis. The data from this analysis is summarized in the tables accompanying the description of each category (e.g., Tables X, XII, XIII, XIV, and XV).

EXAMPLE OF ANALYSIS FORMAT	
TASK:	General and Housekeeping maneuvers.
SUBTASK:	Food handling.
SUBTASK ELEMENT:	Remove 3 food packets from canister No. 1.
DESCRIPTION:	Subject unstows canister No. 1 from compartment A, opens canister, and removes 3 food packets from unit. Subject closes canister and restows unit in compartment A.
TIME INTERVAL: (seconds)	25 seconds.
COMMENTS:	Subject used only handholds when performing this subtask element.

Task.--The task designation identifies the individual major categories specified in the contract. There are four major task categories presented in the order in which they were performed in the water simulation.

(1) General and Housekeeping maneuvers.
(2) Equipment Operations.
(3) Cargo Handling and Stowage.
(4) Experiment Operation.

Subtask.--The subtask category designates the specific maneuver to be performed. In the General and Housekeeping task category, for example, there were 5 subtask maneuvers. Each maneuver was performed as a separate run. These specific subtasks for the General and Housekeeping task were:

(1) don-doff
(2) rest-sleep
(3) food handling
(4) exercise
(5) hygiene

Subtask element.--The subtask element category in the first column of the analysis sheet represents portions of the subtasks which were visually identified and which form the basis for the time-motion analysis. These elements represent the characteristics of the subtasks from which the effect of the various candidate restraints and locomotion aids can be determined.

Description.--The description column comprises a complete breakdown of the procedural steps for each subtask element. This column describes what the subject was required to do, but does not contain a description of the actual performance. Specific information on task performance is given in the following section which includes

sequence photographs as an aid in visualizing the performance. Particularly important aspects of the performance are noted in the comments column of the analysis sheet.

Time intervals.--The time interval column denotes the performance time for the specific subtask element resulting from the water simulation run. The time was measured directly during the test performance or taken from analysis of the 35 mm sequence films or by direct measurement, since 16 mm film coverage was not continuous due to the length of the tasks.

Comments.--The comment column includes the following information:

(1) Subject deviation from actual subtask element procedures.

(2) Important data pertaining to the performance of the particular subtask element.

(3) Notes on the particular restraints and locomotion aids used for the subtask elements, including comments on effectiveness.

(4) Time subtractions for simulation artifacts.

General and Housekeeping

The General and Housekeeping tasks comprise (1) constant wear garment and pressure suit donning and doffing, (2) rest-sleep hardware investigation, (3) food preparation, (4) exercise, and (5) personal hygiene. The task simulation was performed in a serial fashion representing a set of sequential tasks during one duty cycle. All tasks were performed without replication except pressure suit donning. The pressure suit donning task was additionally performed with three variations of compartment sizes to indicate the types of problems involved in exact size interaction specification. Figure 7 presents the general mock-up configuration for the General and Housekeeping task. The main characteristics of the stowage cabinet used for the task variation is shown in Figure 8. The specific contents of the cabinet for each of the task variations is detailed in Table VI.

CWG and FPS don and doff.--The CWG/FPS don and doff simulation involved two operations. First, the donning operation, requiring the unstowage of the appropriate garment and accessories and subsequent suit up maneuver. Second, the doffing operation, comprising the undressing maneuver and subsequent stowage of the garment and accessories. Two operational garments were evaluated; the standard constant wear dress (CWG), and the full pressure suit (FPS) and accessories representative of existing hardware design. Figure 9 illustrates the comparative volume of the work area for the don and doff operations. Work area volume variations were accomplished by moving one wall.

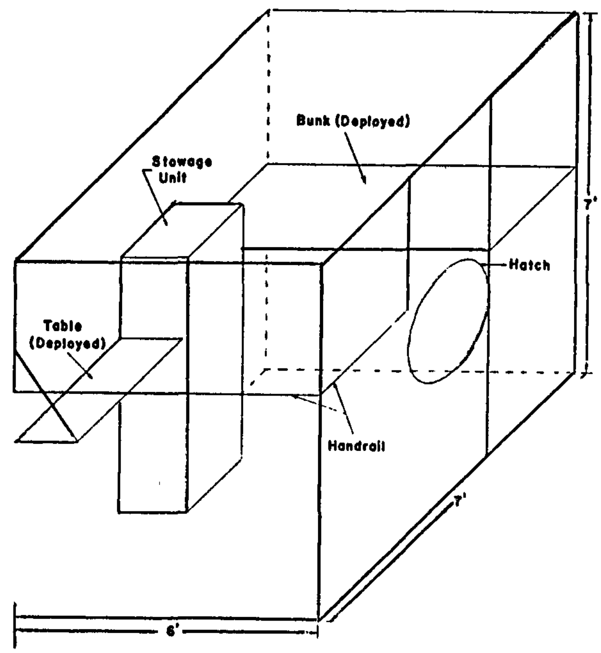


FIGURE 7 - GENERAL & HOUSEKEEPING MOCK-UP CONFIGURATION

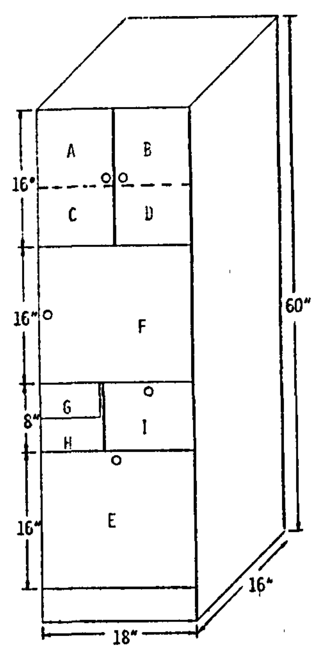


FIGURE 8
COMPARTMENT STOWAGE UNIT

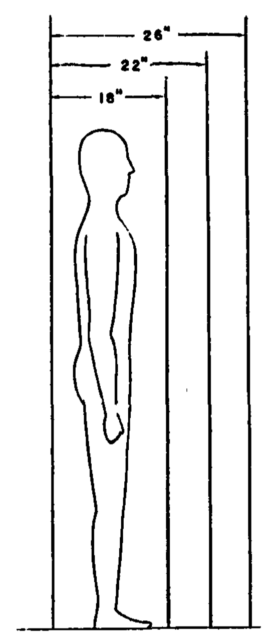


FIGURE 9 - COMPARTMENT WIDTH VARIATION FOR DON-DOFF TASK

TABLE VI

STOWAGE COMPARTMENT CONFIGURATION FOR GENERAL AND HOUSEKEEPING TASKS

AREA	DON & DOFF	REST SLEEP	FOOD HANDLING	EXERCISE	HYGIENE
A	CONSTANT WEAR GARMENT (CWG)	CWG	TYPE 1 & 2 CANISTERS	CWG	PERSONAL LIQUID SOAP
B	RESTRAINT SANDALS (WRS)	WRS	INDIVIDUAL LIQUID UNITS	WRS	PERSONAL HYGIENE MATERIALS
C	STOCKINGS (FPS-S)	FPS-S	INDIVIDUAL FOOD UNITS	FPS-S	PERSONAL HYGIENE MATERIALS
D	UNDERGARMENT (FPS-U)	FPS-U	FOOD TRANS-FER UNIT	FPS-U	STATION HYGIENE MATERIALS
E	FPS	FPS	TYPE 3 FOOD CANISTER	FPS	STATION LIQUID SOAP
F	HEADPIECE (FPS-H)	FPS-H	EMERGENCY FOOD SUPPLIES	FPS-H	STATION HYGIENE MATERIALS
G	GLOVES (FPS-G)	CHECKLIST	CHECKLIST	CHECKLIST	CHECKLIST
H	CHECKLIST	CHECKLIST	CHECKLIST	CHECKLIST	CHECKLIST
I	WASTE	EXERCISER	WATER STORAGE UNIT	EXERCISER	GLOVE-CLOTH

A dressing mirror was mounted on the compartment separation bulkhead adjacent to the equipment stowage panels. A checklist mounting rack was located directly above the mirror. A 15" x 48" female velcro floor patch provided a foot restraint and locomotion aid when the subject stood in front of the mirror or stowage compartments. Velcro restraint sandals, provided with the constant wear garment, and velcro-soled full pressure suit boots completed the foot restraint configuration.

When appropriate, the contents of the stowage compartment were secured by a velcro or snap type restraint. The items in the equipment stowage compartment for the don-doff subtask are listed in Table VII.

During the simulation each compartment was identified by a letter of the alphabet. A waste compartment (coded W) was also provided to dispose of the protective plastic bags in which the equipment was sealed.

TABLE VII

CONTENTS OF THE STOWAGE CABINET

AREA	EQUIPMENT
A	CONSTANT WEAR GARMENT
B	WEIGHTLESS RESTRAINT SANDALS
C	STOCKINGS
D	STANDARD FPS UNDERGARMENT
E	FULL PRESSURE SUIT
F	HEADPIECE (FPS)
G	GLOVES (FPS)
H	DON-DOFF SUIT INTEGRITY CHECKLIST

The dressing simulation began with the subject suited in his constant wear garment. The subject was required tc verify the closing of each compartment unit door after each stowage or unstowage task. The subject was also required to verify that all retaining devices within the compartment units were activated during all don and doff operations.

The FPS donning operation was performed (3) additional times in the reduced dimension chambers; 84" x 84" x 26", 84" x 84" x 22", and 84" x 84" x 18".

Rest-sleep.--An 84" x 72" compartment was designed to simulate the sleeping quarters and included a 72" x 27" personnel couch, shown in Figure 10. The couch was mounted 42" above the compartment floor. The unit had two positions; when not in use the bunk was stowed in the folded position against the compartment bulkhead and, when fully deployed, the unit was horizontal (parallel to the compartment floor). Two adjustable quick release nylon straps were provided to restrain the subject when resting horizontally in the bunk. The subject performed the rest-sleep task simulation wearing the CWG, by removing the weightless restraint sandals before entering the bunk.

Food handling.--Food preparation and eating facilities will be a primary consideration on future space missions. This simulator

evaluates one suggested method of food preparation and handling within the confines of a single compartment configuration. Individual simulated crew member food units were designed to contain a complete meal and provide a portable food station in a zero gravity environment. The personnel food unit (PFU) was prepared in the galley area of the spacecraft or station by each crew member. The unit is reusable and was replenished from supply canisters stored in the galley.

During the preparation of a meal, the subject unstowed the specified individual food canisters, mixed the powder combinations required, and inserted the particular meal of the day in the personnel food unit. The unit was then loaded into a food unit transfer rack and carried to the eating area.

The equipment required for the food preparation, storage, and transfer was stowed in the galley equipment compartments. Equipment required in the galley compartment included a food handling work table that was folded into the compartment bulkhead, when not in use, and a water injector unit. The work table surface was covered with velcro (female). All canisters and food units had male velcro bases. The water injector unit was attached to the water storage unit and the injector was stowed on the storage unit console. Figure 11 shows the 84" x 84" x 72" galley compartment configuration including the equipment stowage unit, work table, menu checklist receptacle, and velcro floor pad. A menu was stored in compartment G of the equipment unit and dictated the proper food amounts and preparations. The menu checklist was unstowed and placed in a wall receptacle prior to the food preparation.

<u>Exercise</u>.--The exercise subtask entailed the performance of various general and isometric warm-up exercises and various conditioning exercises. The exercises were performed with and without the aid of restraints. Both exercise periods were performed in the 84" x 84" x 72" station compartment, Figure 12, and the subject was dressed in the standard constant wear garment and the weightless restraint sandals. A velcro foot pad (15" x 48") was located in the center of the station compartment.

The subject began general and isometric warm-ups by staging on the velcro pad in a standing position. The subject performed both warm-up and conditioning exercises using restraints. After the warm-up exercise period, the modified exerciser was unstowed from the equipment stowage compartment. The conditioning isometric period comprised the following schedule. The subject followed the time schedule precisely, assuming the necessary body positions dictated by the particular exercise.

<u>Hygiene</u>.--Personal hygiene entailed cleansing the body with a glove-cloth while in a simulated zero gravity condition. Two task variations were performed; first, cleansing all points of the body

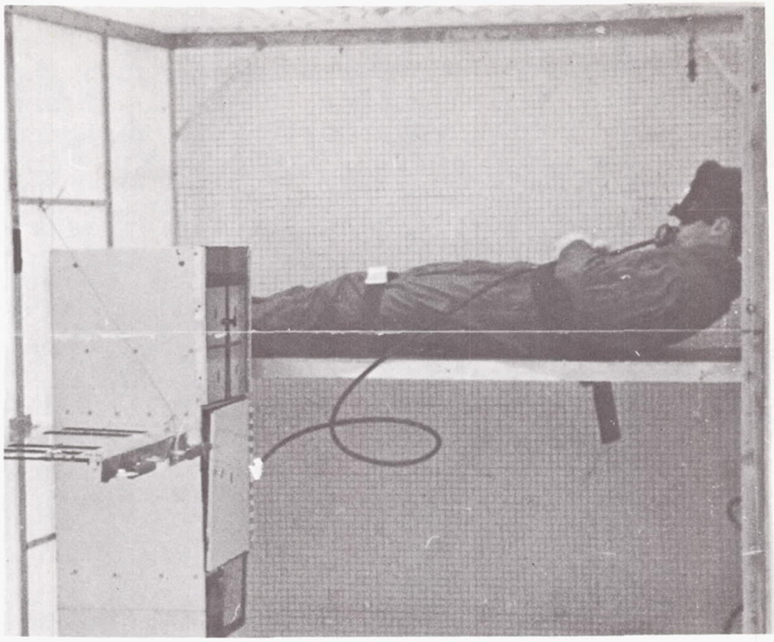


FIGURE 10 - SLEEPING QUARTERS CONFIGURATION

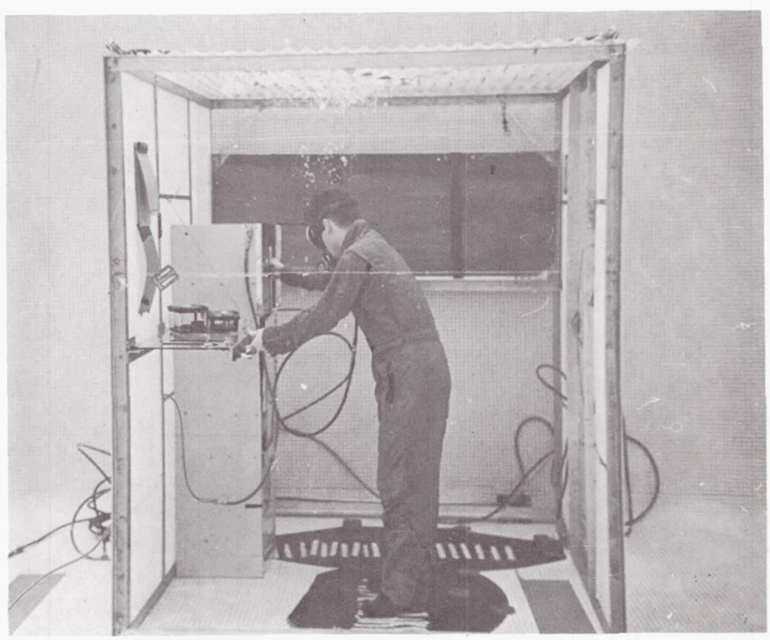


FIGURE 11 - FOOD PREPARATION COMPARTMENT CONFIGURATION

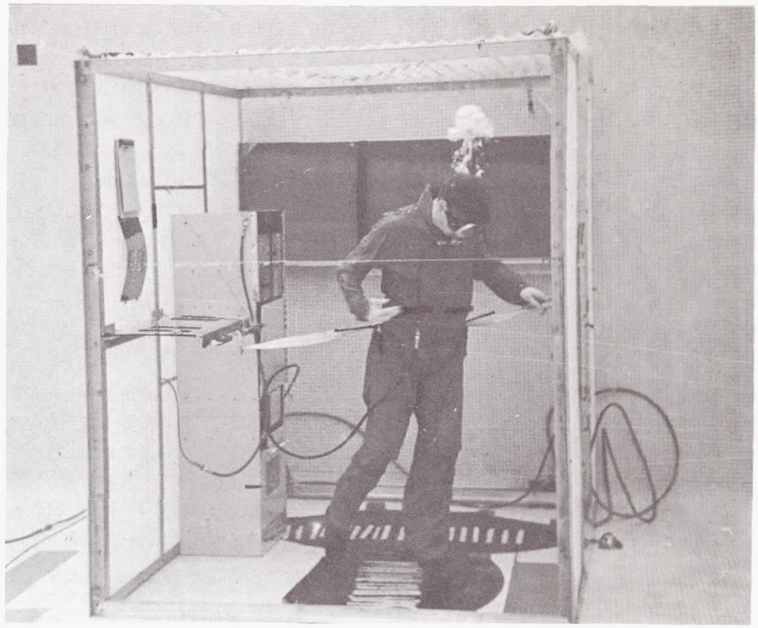


FIGURE 12 - EXERCISE COMPARTMENT CONFIGURATION

while restrained and, second, cleansing all points of the body while in an unrestrained mode.

The subject was suited in a wet suit configuration of minimum thickness and surface area sufficient to attain a neutrally buoyant state. The cloth was a white glove, 3 finger type, and fit on either hand. The subject began the maneuver in his weightless foot restraints on the velcro foot pad. The glove was then unstowed from the equipment compartment and removed from its plastic container. The plastic bag was then discarded in the waste compartment of the equipment unit.

By moving the cloth slowly in vertical movements, the subject attempted to reach all points of his body. The subject was required to maintain his reach on all extreme positions for at least 5 seconds and those positions that were particularly difficult were noted. After covering all positions, the cloth was switched to the left hand and the procedure was repeated.

Preliminary restraint and locomotion aid evaluation.--Prior to the final runs for each major task category, preliminary evaluation runs were performed to evaluate all restraint and locomotion aid systems under consideration during this contract, and to identify the best systems for each final expanded task run.

The General and Housekeeping task comprised many maneuvers. Because of the task length, a number of significant maneuvers were identified, and a task procedure of reduced length was constructed. The significant maneuvers identified are those common to all maneuvers in the task. These maneuvers are divided into two types, anthropomorphic maneuvers and equipment maneuvers. The anthropomorphic maneuvers include body transfer, bending, and reaching. The equipment maneuvers include small parts manipulation, small parts transfer, module manipulation and transfer. Table VIII indicates the particular maneuvers that were involved in the various steps (elements) of the subtask.

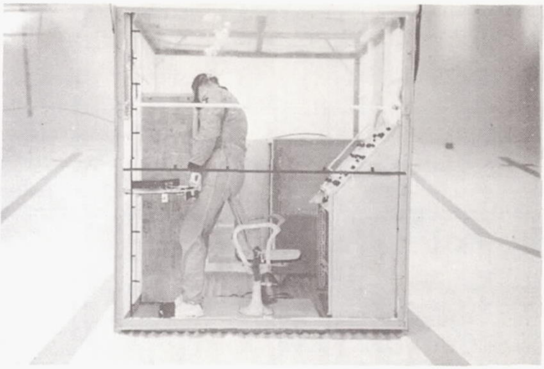
The preliminary run provided a mode for the qualitative evaluation of the following restraint and locomotion aids. The restraints evaluated were as follows: positive foot restraints, velcro sandals, toe traps, chair and seat belt, waist tether (1), and waist tethers (2). The locomotion aids used were: handholds, handrails, velcro, and soaring. These restraints and locomotion aids are shown in Figures 13 and 14. An evaluation run was also performed without restraints or locomotion aids

The subject was instructed to perform a repetitive evaluation using a different set of the restraint and locomotion aids in a separate run. The subject was instructed to make restraint connections immediately upon entering the compartment. For example, when performing the task with waist tethers, the subject made his two tether connections immediately and then removed his right tether for the next step of his task because he could not perform this step with both tethers attached. When performing the <u>No Restraint</u> evaluation, the subject simply moved into position at his work station area and proceeded on to his next task step.

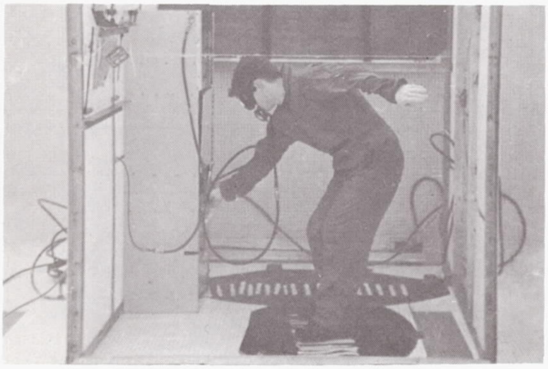
The restraint and locomotion aid systems were evaluated using the rating matrix shown in Table IX. The columns list the subtask elements and the rows list the restraint and locomotion aid candidates evaluated for the General and Housekeeping tasks. A numerical rating system was used to classify the restraint and locomotion systems in terms of the most to least desirable aid for each maneuver. Maneuvers for which the restraints or locomotion aids were not applicable were marked NA. The values for the rating system were: (1) poor, (2) fair, (3) good, and (4) excellent. Zero value was assigned to any maneuver for which the particular system could not be used.

The average of the rows was calculated using only the positions marked with a numerical rating or zero. A percentile rating was then calculated. Using the results of the percentile rating, the most applicable restraints and locomotion aids were selected for the final subtask run.

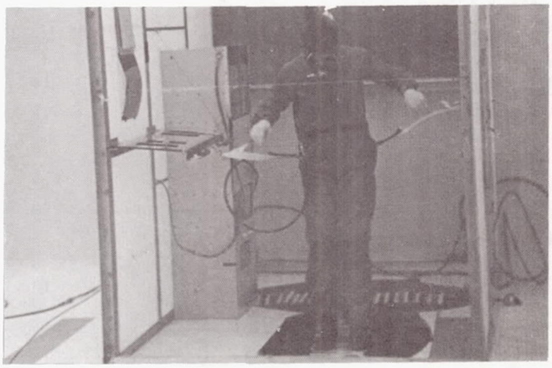
CHAIR AND SEAT BELT



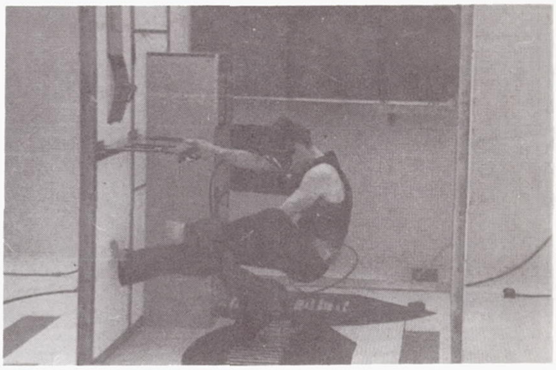
POSITIVE FOOT RESTRAINT
AND TOE TRAPS



VELCRO SANDALS
FOOT RESTRAINT



WAIST TETHERS



HANDHOLDS

FIGURE 13 - RESTRAINT AIDS USED IN THE SIMULATION

TABLE VIII - SIGNIFICANT PERFORMANCE CHARACTERISTICS

	BODY TRANSFER	BENDING	REACHING	PARTS HANDLING	PARTS TRANSFER	MODULE HANDLING	MODULE TRANSFER
ENTER HATCH	X	-	X	X	-	-	-
MOVE TO CABINET	X	-	-	-	-	-	-
UNSTOW CHECKLIST	-	-	X	X	X	-	-
UNSTOW WORK TABLE	-	-	X	X	-	-	-
TOUCH TOES	-	X	X	-	-	-	-
UNSTOW FLIGHT SUIT	-	X	X	-	-	-	X
DON FLIGHT SUIT	-	X	X	X	-	X	-
POSITION AT WORK TABLE	X	-	-	-	-	-	-
UNSTOW FOOD CANISTER	-	-	X	-	X	-	-
UNSTOW PFU	-	-	X	-	X	-	-
UNSTOW FOOD PACKET	-	-	-	X	-	-	-
RESTOW FOOD CANISTER	-	-	X	-	X	-	-
TRANSFER THROUGH HATCH	X	-	X	X	-	-	X

STATIONARY HANDRAIL

PORTABLE HANDRAIL

SOARING HANDHOLD

SOARING

FIGURE 14 - MOTION AIDS USED IN THE SIMULATION

TABLE IX EVALUATION MATRIX FOR GENERAL & HOUSEKEEPING TASKS

	RESTRAINTS								MOTION AIDS			
	VELCRO FOOT RESTRAINTS	HANDHOLDS	TETHERS (2)	TETHER (1)	CHAIR	POSITIVE FOOT RESTRAINTS	TOE TRAPS	NO RESTRAINTS	HANDRAILS	HANDHOLDS	SOARING	VELCRO FOOT RESTRAINTS
ENTER HATCH	0	3	0	N	0	0	0	1	N	N	N	N
TO CABINET	N	N	N	N	N	N	N	N	1	3	4	0
UNSTOW CHECKLIST	3	3	2	2	1	2	2	1	N	N	N	N
UNSTOW WORKTABLE	3	4	2	2	1	2	2	2	N	N	N	N
EXERCISE #1	3	0	2	1	0	1	2	3	N	N	N	N
EXERCISE #2	3	0	2	1	0	1	2	3	N	N	N	N
UNSTOW CWG	3	3	1	2	1	2	2	2	N	N	N	N
DON CWG	2	3	0	1	0	1	1	4	N	N	N	N
TO WORKTABLE	N	N	N	N	N	N	N	N	1	3	0	3
UNSTOW CANISTER	3	3	1	2	1	2	2	1	N	N	N	N
UNSTOW PFU	3	3	1	2	1	2	2	1	N	N	N	N
REMOVE PACKET	3	3	2	2	1	2	2	2	N	N	N	N
FILL PFU	3	3	2	2	2	2	2	2	N	N	N	N
CLOSE PFU	3	3	2	2	2	2	2	2	N	N	N	N
RESTOW CANISTER	3	3	1	2	1	2	2	1	N	N	N	N
UNSTOW FTU	3	4	0	1	0	1	2	1	N	N	N	N
FILL FTU	3	3	2	2	2	2	2	1	N	N	N	N
REMOVE FTU	4	3	2	2	2	2	2	1	N	N	N	N
TO HATCH	N	N	N	N	N	N	N	N	1	2	2	3
EXIT HATCH	N	N	N	N	N	N	N	N	1	3	2	0
RATING (0-100)	71	69	34	41	23	45	33	44	25	50	38	41

N - NOT APPLICABLE

A combination of the two restraint systems, velcro sandals and handholds, was chosen for the final runs of the General and Housekeeping tasks. Because these systems corresponded closely with the most preferred locomotion aids, they were also used as the locomotion systems for the final General and Housekeeping runs. The evaluation matrix shows, however, that certain maneuvers were best performed with the aid of other restraints. For this reason additional restraints and locomotion aids were used where appropriate in the final runs. Examples of this were the use of two waist tethers in the exercise subtask and the use of toe traps in portions of the don-doff subtask.

The results of the classification rated the restraints and locomotion aids in the following order (most preferred system first, etc.).

RESTRAINT	LOCOMOTION AID
1. Velcro sandals	1. Handholds
2. Handholds	2. Soaring
3. Toe traps	3. Velcro sandals
4. No restraints	4. Handrails
5. One waist tether	
6. Positive foot restraints	
7. Two waist tethers	
8. Chair-seat belt	

Results of the final subtask runs for the General and Housekeeping task category.--Upon completion of the preliminary restraint and locomotion aid evaluation, a final run was made using the restraint and locomotion aids adjudged most applicable in the preliminary runs. The important aspects of this final run were recorded on motion picture film and by means of a continuous 35 mm sequence. Pertinent observations of the subject and test observers were recorded. The following section describes the performance of the subtasks comprising the General and Housekeeping task and presents the results derived from each subtask.

Don-doff: The performance analysis of the don-doff subtask is presented in Table X which identifies the major subtask elements and denotes the time intervals for each. Pertinent comments are given as described in the data format description previously given. Sequence pictures are included with appropriate references in the textual material to aid in evaluating the task performance. Table XI summarizes the major subtasks and denotes the cumulative performance times for each. Subsequent to the run in the large

TABLE X.--PERFORMANCE ANALYSIS OF DON AND DOFF SUBTASK †

SUBTASK ELEMENT	DESCRIPTION	TIME SEC.	COMMENTS
UNSTOW, INSERT CHECKLIST IN RECEPTACLE.	REMOVES CHECKLIST FROM STORAGE COMPARTMENT H AND INSERTS LIST IN BULKHEAD RECEPTACLE.	105	TASK TIME BEGINS WHEN SUBJECT BEGINS TO UNSTOW CHECKLIST FROM EQUIPMENT CABINET, COMPARTMENT H. RESTRAINTS USED FOR FINAL RUN ARE VELCRO SHOES AND HANDHOLDS.
DOFF AND STOW WRS.	REMOVES WEIGHTLESS RESTRAINT SANDALS (WRS) AND STOWS THEM IN COMPARTMENT B.		
DOFF AND STOW STOCKINGS.	REMOVES STOCKINGS AND STOWS THEM INSIDE WRS IN COMPARTMENT B.		
DOFF AND STOW CWG.	REMOVES CONSTANT WEAR GARMENT (CWG), FOLDS GARMENT AND STOWS IN COMPARTMENT A.	75	
UNSTOW AND DON UNDERGARMENT.	UNSTOWS UNDERGARMENT FROM COMPARTMENT C, REMOVES AND DISPOSES OF PROTECTIVE BAG IN WASTE COMPARTMENT W. DONS UNDERGARMENT.		THIS SUBTASK IS NOT PERFORMED IN THE FINAL RUN.
UNSTOW FPS.	REMOVES FULL PRESSURE SUIT FROM STORAGE COMPARTMENT D, REMOVES AND DISCARDS PROTECTIVE BAG IN WASTE COMPARTMENT W.	70	
DON FPS.	DONS FPS AFTER VISUALLY INSPECTING SUIT. REGAINS STANDING POSITION IN COMPARTMENT	140	† ref. fig. 14

TABLE X.--PERFORMANCE ANALYSIS OF DON AND DOFF SUBTASK - CONTINUED

SUBTASK ELEMENT	DESCRIPTION	TIME SEC.	COMMENTS
CLOSE ZIPPERS.		105	FILM SHOWS USE OF RESTRAINTS HERE.
UNSTOW AND DON FPS HELMET.	REMOVES FPS HELMET FROM STORAGE COMPARTMENT E, DONS AND MATES LOCKING MECHANISM TO SUIT. VERIFIES SECURE.	60	45 SECONDS ARE SUBTRACTED FROM TIME INTERVAL FOR EFFECTS OF SIMULATION (AIR REGULATOR) TRANSFER THROUGH HELMET AND FACE MASK TRANSFER AND POSITIONING.
UNSTOW AND DON FPS GLOVES.	REMOVES GLOVES FROM STORAGE COMPARTMENT F, DONS AND MATES LOCKS TO SUIT. VERIFIES SECURE.	105	75 SECONDS ARE SUBTRACTED FROM TIME INTERVAL FOR INCORRECT PROCEDURE BY SUBJECT.
SUIT INTEGRITY CHECKOUT.	USING MIRROR, PERFORMS SUIT INTEGRITY CHECK ON FOLLOWING ITEMS: ZIPPERS, HELMET, GLOVES, TIEDOWNS, SUIT PORTS.	135	TASK TIME COMPLETED WHEN SUBJECT RESTOWS CHECKLIST IN COMPARTMENT H.
UNSTOW CHECKLIST.	REMOVES SUIT DOFFING CHECKLIST FROM COMPARTMENT H AND PLACES IN BULKHEAD RECEPTACLE.	20	TASK TIME BEGINS AS SUBJECT UNSTOWS DOFFING CHECKLIST FROM COMPARTMENT H.
DOFF AND STOW FPS GLOVES.	RELEASES ALL SUIT TIEDOWNS. REMOVES FPS GLOVES AND STOWS IN COMPARTMENT F.	70	
DOFF AND STOW FPS HELMET.	REMOVES FPS HELMET AND STOWS IN COMPARTMENT E. VERIFIES SECURE.	30	20 SECONDS SUBTRACTED FROM TIME INTERVAL FOR EFFECTS OF WATER SIMULATION (AIR SYSTEM AND MASK TRANSFER THROUGH HELMET).

TABLE X.--PERFORMANCE ANALYSIS OF DON AND DOFF SUBTASK - CONTINUED

SUBTASK ELEMENT	DESCRIPTION	TIME SEC.	COMMENTS
DOFF FPS. (a)	OPENS SUIT ZIPPERS AND REMOVES TOP OF FPS.	70	15 SECONDS ARE SUBTRACTED FROM TIME INTERVAL FOR EFFECTS OF WATER SIMULATION.
DOFF FPS. (b)	REMOVES BOTTOM OF FPS.	75	20 SECONDS ARE SUBTRACTED FROM TIME INTERVAL FOR EFFECTS OF WATER SIMULATION.
DOFF FPS. (c)	STOWS FPS IN COMPARTMENT D.	120	FILM SHOWS PROBLEMS ENCOUNTERED HERE WHEN PERFORMING THIS SUBTASK ELEMENT WITHOUT RESTRAINTS. NO FILM (MOVIE) AFTER THIS SUBTASK ELEMENT.
DOFF UNDERGARMENT AND STOW.	REMOVES UNDERGARMENT, FOLDS, AND STOWS IN COMPARTMENT H.	--	THIS SUBTASK IS NOT PERFORMED IN THE FINAL RUN.
UNSTOW AND DON CWG.	REMOVES CONSTANT WEAR GARMENT (CWG) FROM COMPARTMENT A. DONS CWG.	75	
UNSTOW AND DON STOCKINGS.	REMOVES STOCKINGS FROM WRS IN COMPARTMENT B AND DONS.	90	
UNSTOW AND DON WRS.	REMOVES WRS FROM COMPARTMENT B AND DONS.		
STOW CHECKLIST	REMOVES CHECKLIST FROM BULKHEAD RECEPTACLE AND STOWS IN COMPARTMENT H.	15	

TABLE XI.--MAJOR SUBTASK ELEMENTS OF DON AND DOFF SUBTASK †

SUBTASK ELEMENT	DESCRIPTION	TIME SEC.	COMMENTS
DOFF CWG AND ACCESSORIES AND STOW.	SUBJECT REMOVES CONSTANT WEAR GARMENT, WEIGHTLESS RESTRAINT SANDALS AND STOCKINGS AND STOWS ITEMS IN STORAGE COMPARTMENTS.	250	
UNSTOW AND DON FPS AND ACCESSORIES.	SUBJECT UNSTOWS FPS (FULL PRESSURE SUIT), DONS BOTTOM PORTION OF SUIT, DONS TOP, CLOSES ZIPPERS, UNSTOWS AND DONS HELMET AND GLOVES.	470	120 SECONDS ARE SUBTRACTED FROM TIME INTERVAL FOR EFFECTS OF WATER SIMULATION.
FPS INTEGRITY CHECKOUT.	USING MIRROR AND CHECKLIST, SUBJECT CHECKS FOLLOWING ITEMS: ZIPPERS, HELMET, GLOVES, TIEDOWNS, AND SUIT FITTINGS.	135	
DOFF FPS AND ACCESSORIES AND STOW.	SUBJECT DOFFS GLOVES, HELMET, OPENS SUIT ZIPPERS, RELEASES TIEDOWNS, DOFFS FPS, AND STOWS EQUIPMENT IN STORAGE UNIT.	285	35 SECONDS ARE SUBTRACTED FROM TIME INTERVAL FOR EFFECTS OF WATER SIMULATION.
UNSTOW AND DON CWG AND ACCESSORIES.	SUBJECT UNSTOWS AND DONS CONSTANT WEAR GARMENT, STOCKINGS, AND WEIGHTLESS RESTRAINT SANDALS.	165	
			(TOTAL TIME FOR THE DON AND DOFF SUBTASK: 1,305 SECONDS.)

† ref. fig. 14

volume compartment, a series of runs in reduced volume compartments was performed to quantitatively assess the effect of compartment volume in performance.

The subject began the don and doff subtask staged in front of the deployed work table and compartment stowage unit (CSU), Figure 15. He began the subtask by unstowing the donning and suit integrity checklist from compartment H and inserting the checklist on the bulkhead receptacle. The updated donning and suit integrity checklist was used on this final don-doff subtask run. The subject's restraint and locomotion aid systems were the velcro floor and sandal system and the handholds. He was suited in his constant wear garment (CWG) and the velcro sandals. Immediately following insertion of the checklist on the bulkhead, the subject began to remove his weightless restraint sandals (WRS). Holding the left handhold on the table to maintain his position, the subject removed his left sandal, Figure 16a. He then opened compartment B of the CSU and stowed the sandal, verifying that it was secure on the velcro-lined shelf. Using the open door of compartment B as a handhold, the subject removed his right weightless restraint sandal. He removed the sandal with his left hand and placed it in compartment B, next to the left sandal. Again using the door as a handhold, the subject removed his left stocking and placed the left stocking inside the left sandal in compartment B. When removing the left stocking, the subject's feet drifted off the floor. He maintained his position, however, by holding onto the compartment B door.

After removing the right stocking and placing it in the right restraint sandal in compartment B, the subject closed the compartment and regained his position in front of the work table using the handholds on the table edge. The subject positioned his feet, at this time, not on the velcro floor pad but slightly forward of this pad, almost underneath the work table, Figure 16b. Nevertheless, with only a light handgrip on the table handholds, he was able to maintain his position. He next unzipped his flight suit with his right hand and began to pull it off his shoulders. He changed hands and pulled the other shoulder free and removed the flight suit from his body using his right hand as a handhold on the table to maintain position. The subject released both handholds and drifted free while he pulled the remainder of the flight suit off over his legs, Figure 16c. He folded the flight suit using no restraints. The subject then opened compartment A.

At this point in the task the subject was, in effect, drifting in the center of the compartment with only a light hold on compartment A door. Using the door and the cabinet itself for positioning, the subject placed the flight suit in the compartment and secured it with a velcro strap. He then closed compartment A door and repositioned himself in a standing position in front of the work table, using the table handholds to accomplish this maneuver.

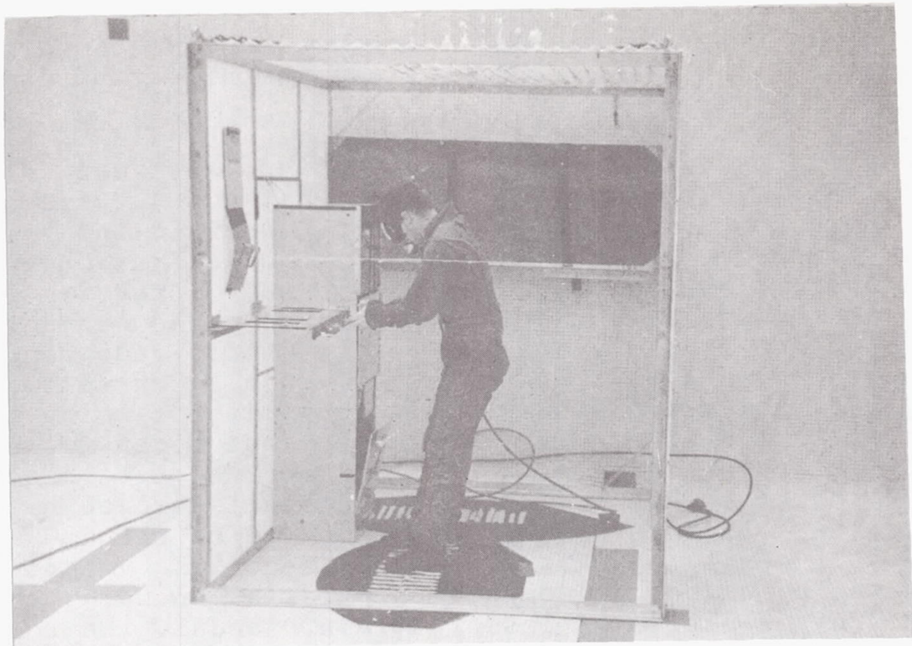


FIGURE 15 - SUBJECT STAGING FOR THE DON-DOFF SUBTASK

Due to the tight fit of the full pressure suit, the next step in the donning checklist, that of donning the full pressure suit undergarment, was omitted from the task. In preliminary runs the undergarment proved to be a hindrance when donning the extremely tight FPS. Since this factor was considered not a problem with a properly fitted suit, the undergarment was omitted from the task. The subject thus proceeded to step 6 of the donning checklist, unstowing the full pressure suit. The subject opened compartment D and removed the protective plastic bag containing the full pressure suit. Due to the size of the package and its interreaction with the cabinet, the handhold appeared to be a definite asset to this maneuver, Figure 16d. Even with the aid of the handhold the subject's position was disrupted momentarily while he tried to pull the package out of compartment D. After removing the package from compartment D, the subject released his handhold and, while floating free, broke the seal on the package and removed the full pressure suit from its protective plastic bag. He then reached down and opened the waste compartment and disposed of the plastic bag. The subject visually inspected the full pressure suit and made the necessary adjustments prior to donning.

The subject assumed a sitting position slightly above the floor of the compartment and began to don the suit, free of any restraints, Figure 16e. While donning the bottom portion of the FPS, he encountered some difficulty in placing his legs completely into the

boots. This was due almost entirely to the fact that the suit was not a proper fit. However, effects of the water-filled legs may have had some effect on the maneuver. From a semi-sitting position the subject leaned back and pulled the suit up on his body. He then arranged the upper portion of the suit torso and inserted his arms and then his head into the suit.

The subject placed his feet on the velcro pads and regained his semi-sitting position leaning back at approximately a 45 degree angle against the compartment wall, Figure 16f. From this position he began to close the suit zipper. Before completing the zipper closure, the subject pushed off the compartment wall with his hand and assumed an erect stance on the foot restraints using the table to stop his forward motion. From this position he completed closing the zipper. The subject, at this time, was using only the velcro foot restraints to maintain his position, Figure 16g.

Next, the subject opened compartment E and removed the full pressure suit helmet. He neglected to close the compartment, however, and immediately began to don the helmet. This task maneuver was hampered by the fact that the subject had to remove and replace his face mask and air regulator to don this headpiece. After donning the helmet the subject reached forward and pulled himself into a standing position at the table. From this position he engaged the helmet to the suit neckring and locked it into position. The subject noticed, at this point, that he neglected to close compartment E. He closed the door and then immediately opened compartment F and unstowed the full pressure suit gloves. Holding the gloves and the left handhold with his left hand, the subject closed compartment F with his right hand. He then regained his position and donned the right and left gloves.

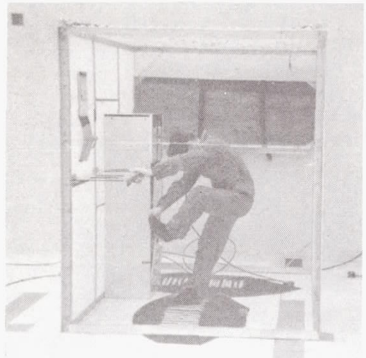
Upon completion of the glove donning, the subject began his suit integrity checkout. The subject read the checkout steps individually. The subject used the convex mirror, when necessary, and particularly for this first step, Figure 16h. After verifying his gloves secure, he checked his neck zippers and his suit zipper, again using the mirror to verify these items. Upon completion of these steps, the subject made the final suit tiedown adjustments in preparation for pressurizing the suit. Finally, the subject removed the donning and suit integrity checklist from the bulkhead receptacle and filed the checklist in compartment H. At this point the donning task ended.

Immediately following stowing of the donning checklist, the subject removed the doffing checklist and inserted it in the bulkhead receptacle. The subject pushed off the velcro foot pad to reach the checklist receptacle. The subject remained free of the foot restraints while removing his gloves and stowing them in compartment F. He then detached his helmet from the suit, doffed the unit, and placed the helmet in compartment E. The subject failed to completely

close the door on compartment E and, as he moved back into position to doff his suit, the door swung freely open. Regaining his stance on the velcro foot pads, the subject released his pressure suit zipper. He encountered no difficulty in performing this maneuver. He placed his body in a sitting position with his back to the compartment wall containing the hatch and, from this position, he began to remove the upper portion of his full pressure suit. The subject used his velcro floor restraint as an aid in placing himself in a sitting position, Figure 16i. Since it has been noted in previous runs that the velcro was not very helpful for this type of positioning, it is possible that he had a slight negative buoyancy which allowed him to perform this maneuver.

The subject next removed the bottom portion of the suit from his legs. He noted that this maneuver was the most difficult portion of the subtask. This may have been due to the tight fit of the suit legs. The subject allowed the full pressure suit to remain on the floor of the compartment and, for the first time during this task, assumed an upside-down position in the compartment with his feet towards the compartment ceiling, Figure 16j. He used the handholds provided on the compartment stowage unit to maintain his position. Moving from the position to a horizontal position with his feet on the bulkhead containing the hatch, the subject began to fold the full pressure suit in preparation for stowage. He then opened compartment D of the CSU and stowed the suit in this compartment. As previously noted the FPS undergarment was not used in the final run of the don-doff subtask. The subject regained his standing position using the left handhold on the work table. He then unstowed his CWG from compartment A. He released his handhold and donned the CWG while floating free. The subject regained his standing position, opened compartment B, and removed and donned his stockings, Figure 16k. He then removed and donned the weightless restraint sandals. These maneuvers were performed without the aid of restraints. Finally, regaining his original standing position with the aid of the work table handholds, the subject removed and restowed the checklist in compartment H, Figure 16l. At this point the subtask ended.

The don-doff subtask was performed three more times using various compartment sizes. The results of the study effort indicated that a 26 inch wide compartment presented a logical starting point for the size variation runs. The first compartment dimensions used were 84" x 84" x 26". This compartment volume was 105.8 cu ft. The don-doff maneuver was performed easily in this space. Two more reduced volumes were used; an 89.7 cu ft compartment and a 73.5 cu ft compartment. The comparative sizes are shown in Figure 17. The height and depth dimensions of 84" were maintained constant for each of the three compartment volumes. The compartment widths for the last two volume variations were 22 inches and 18 inches, respectively.



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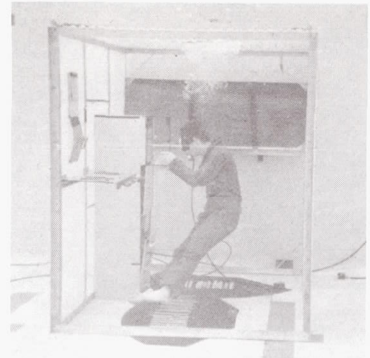

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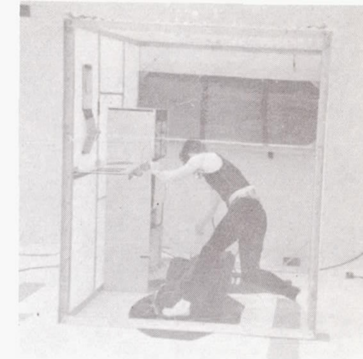

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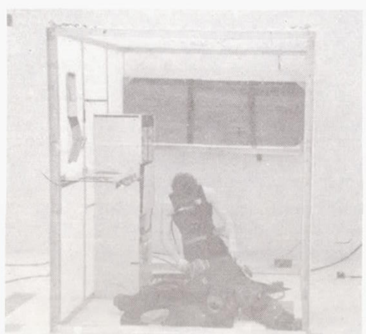

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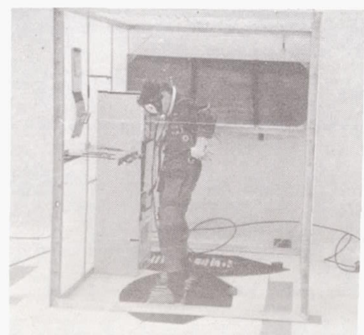

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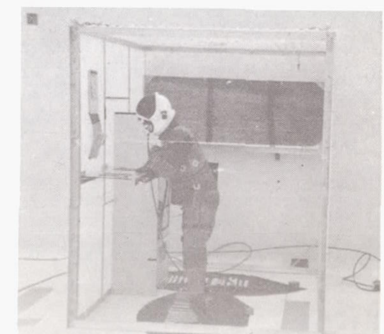
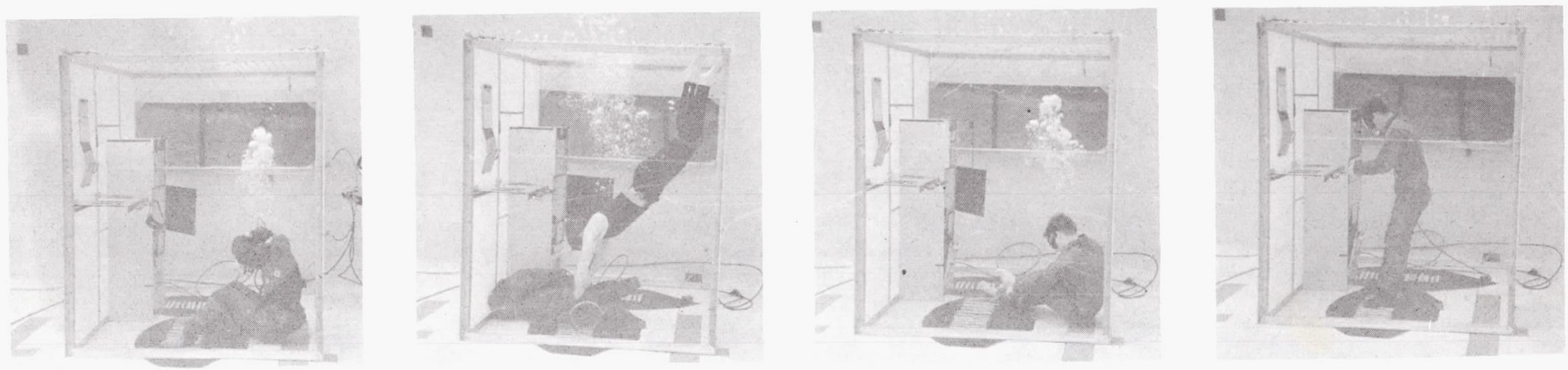


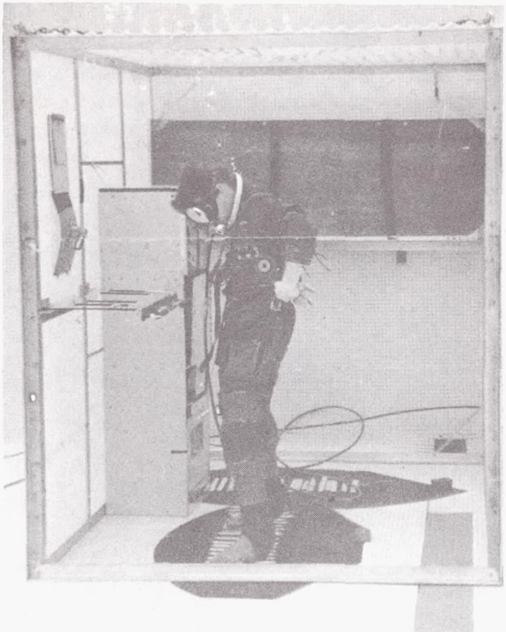
H

FIGURE 16 - SEQUENCE OF DON-DOFF SUBTASK

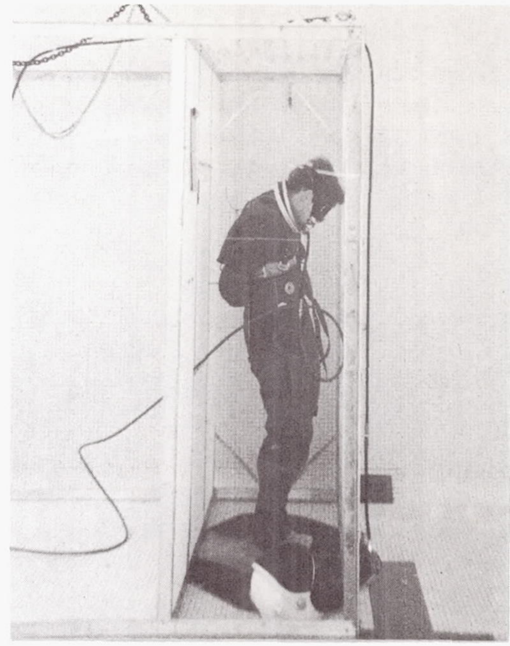


I J K L

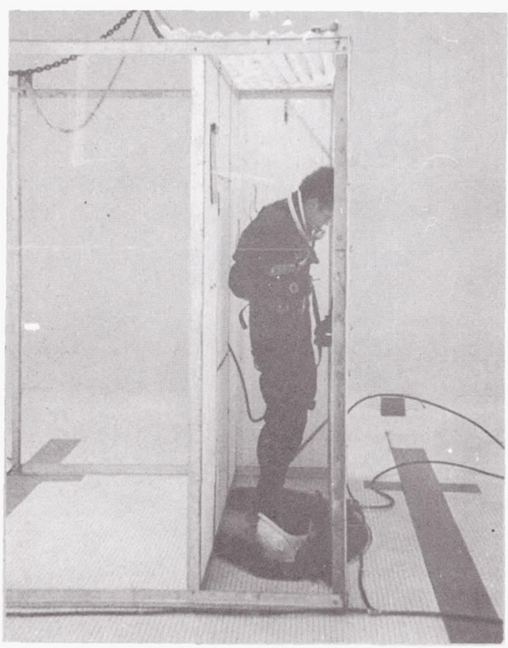
FIGURE 16 - SEQUENCE OF DON-DOFF SUBTASK-CONTINUED



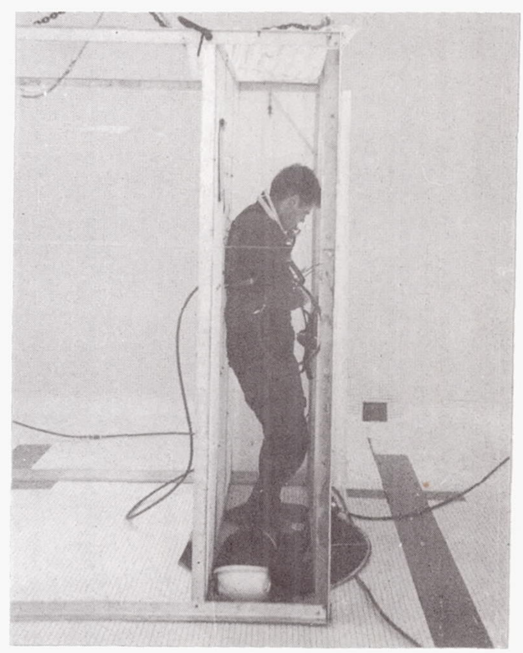
72"



26"



22"



18"

FIGURE 17 - DON-DOFF SUBTASK COMPARTMENT WIDTH VARIATION

A shortened version of the don-doff maneuvers employing only the full pressure suit (FPS) was used in the volume variation runs. The following is a description of this shortened don-doff procedure indicating the variations from the complete don-doff subtask performed in the 84" x 84" x 72" or the 294 cu ft compartment volume.

The subject began the subtask staged in the dressing compartment. He performed the subtask elements in the same order and manner in all three compartment volume variations. The FPS and accessories were secured beside the subject on the compartment floor. The order of suit donning was as follows: FPS torso bottom, FPS torso top, close suit zipper, FPS headpiece, and FPS gloves.

After donning the suit bottom the subject inserted his feet in the positive foot restraints. From this point on the subject remained in the positive foot restraints until the end of the suit doffing portion of the don-doff subtask. When removing the suit bottom the subject removed his feet from the restraints. The suit doffing procedure was as follows: remove FPS gloves, remove FPS headpiece, open FPS zipper, remove FPS torso top, and remove FPS torso bottom. The subtask ended with the removal of the FPS bottom.

Figure 18 is a comparison of the subtask element time intervals and the subtask total times for the various compartment volumes. From this data it is seen that the total don-doff subtask time decreases

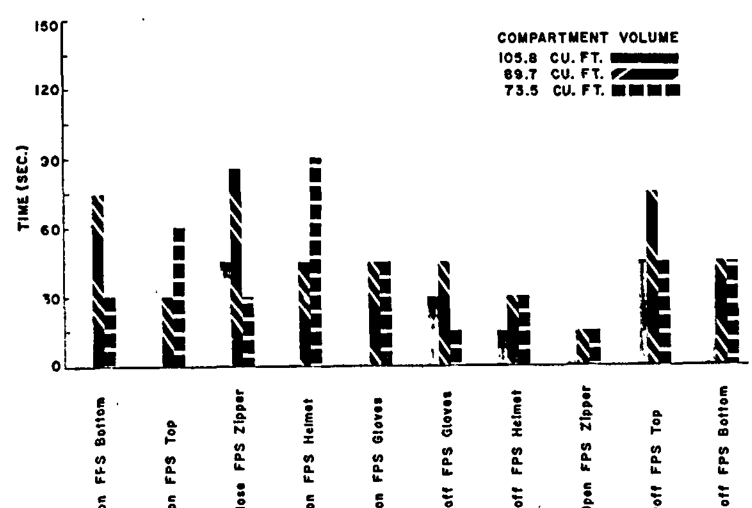


FIGURE 18 - THE EFFECT OF COMPARTMENT VOLUME ON DON-DOFF SUBTASK

as the compartment volume decreases. The data suggests that the don-doff maneuvers are performed more efficiently in a small, confined area. Past experience has shown that, in some cases, working in confined areas in zero gravity conditions does increase efficiency because of the added points of stability afforded by compartment walls and protuberances. It is also known from preliminary evaluations during this contract that the positive foot restraints are sufficient within themselves to eliminate the need for any additional points of stability for this type of task. The positive foot restraints should have canceled out the effect of the volume changes on the subtask time. The data does not support this conclusion. It is suggested that other factors may be involved. One such factor could be task performance experience, i.e., task time decreases due to learning by repetitive performance. Past experience indicates that this factor should not have affected the subtask times. The subject had performed this maneuver a number of times before the final subtask runs, and his experience in this type of maneuver was extensive. It is interesting, however, that the first donning maneuvers in the largest volume compartment took almost twice as long as don-doff in the smaller volume compartments.

The following conclusions have been drawn from the simulation and analysis. First, that in the smaller confined compartment volumes the don-doff maneuver could be performed more effectively and efficiently because of the increased number of points of stability. Second, the 18 inch compartment width is a minimum for this type of maneuver. Figure 19 shows the relationship of don-doff time to compartment volume and exhibits the inverse relation of time to volume. A suggested compartment volume for a six-foot subject might be 27.0 cu ft or 72" x 36" x 18". The height and depth estimates were taken from visual observation of the subtask maneuvers. Third, although the positive foot restraints were shown to be very helpful in the don-doff maneuvers when the larger compartment size did not afford contact points for the subject, these restraints became less effective when don-doff maneuvers were performed in the more confined compartment areas.

Rest-sleep: Since the water immersion simulation technique precludes the evaluation of the psychological and physiological aspects of rest-sleep in weightless environments, the intent of this simulation was to investigate the spatial aspects of the rest-sleep compartment size and to assess the effect and comfort of several restraint systems.

Table XII presents the performance analysis of the rest-sleep subtask, noting the time intervals and the pertinent comments for the subtask elements consisting of the various resting positions evaluated by the subject. Three basic resting positions were evaluated during this subtask. These were the face-down position, the side position, and the back position shown in Figure 20. In addition

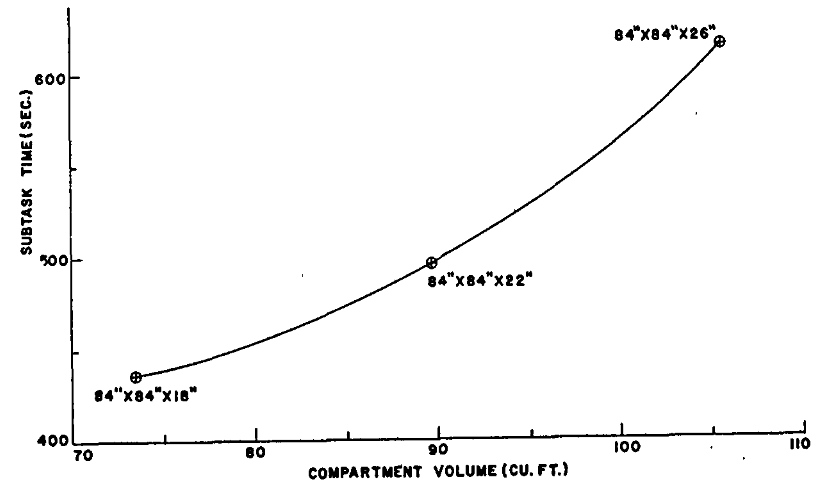


FIGURE 19 - TIME-VOLUME COMPARISON FOR FPS DON-DOFF

to the basic evaluation of the resting positions using the chest and thigh seat belt type restraint system, bed deployment entry-exit were also evaluated. The following is a complete description of the subtask, including pertinent observations from the performance analysis.

The subject began the rest-sleep subtask staged in front of the stowed bunk on the rear compartment wall, Figure 21a. He pushed free of the floor position and, using the handhold on the edge of the bunk, pulled himself up to the locking mechanism and then, maintaining his floating position, reached for a handhold adjacent to the hatch and pulled the bunk into the deployed position. The subject locked the right locking mechanism and then using the handrail on the edge of the bunk for a locomotion aid, moved to the left side of the bunk and activated the left locking mechanism, Figure 21b.

The subject encountered no difficulty in activating either locking mechanism while maintaining only a light handhold on the bunk itself. Following activation of the locking mechanisms, the subject released the left and right belt restraints which were secured to the bunk in a tightened position, Figure 21c. The subject then removed his left and right weightless restraint sandals and secured the sandals to the velcro floor. The subject encountered no difficulty on this maneuver. He held on to the bunk handrail and

TABLE XII.--PERFORMANCE ANALYSIS OF REST-SLEEP SUBTASK †

SUBTASK ELEMENT	DESCRIPTION	TIME SEC.	COMMENTS
DEPLOY BUNK.	DEACTIVATES STOWED BUNK LOCKING MECHANISM (RIGHT HAND CORNER OF STOWED BUNK). UNSTOWS BUNK AND ACTIVATES LEFT AND RIGHT DEPLOYED BUNK LOCKING MECHANISMS.	32	SUBJECT USES HANDHOLD ON EDGE OF BUNK TO REACH STOWED LOCKING MECHANISM. HE IS FREE OF THE VELCRO FOOT RESTRAINTS, HOLDING ON WITH HIS LEFT HAND ONLY.
OPEN BELT RESTRAINTS.	UNSTRAPS CHEST AND THIGH RESTRAINTS.	14	FLOATING ABOVE COMPARTMENT FLOOR, SUBJECT HOLDS ONTO BUNK WITH ONE HAND WHILE UNSTRAPPING RESTRAINTS.
REMOVE WRS.	REMOVES WEIGHTLESS RESTRAINT SANDALS (WRS) AND SECURES THEM TO VELCRO FLOOR.	28	SUBJECT FLOATS COMPLETELY FREE WHILE REMOVING RESTRAINTS IN A SEMI-SITTING POSITION.
MOUNT BUNK.	MOVES INTO DEPLOYED BUNK AND ASSUMES A SITTING POSITION WITH LEGS STRETCHED OUT ON BUNK.	22	SUBJECT EASILY MANEUVERS INTO BUNK USING ONLY LIGHT HANDHOLDS AND PUSH/PULL ON THE BUNK STRUCTURE AND RESTRAINT BELTS.
ATTACH THIGH RESTRAINT.	ATTACHES AND TIGHTENS THIGH RESTRAINT OVER UPPER LEGS IN MOST COMFORTABLE POSITION.	11	
ATTACH CHEST RESTRAINT.	ASSUMES A PRONE POSITION ON BUNK AND ATTACHES AND TIGHTENS CHEST RESTRAINT IN MOST COMFORTABLE POSITION.	11	SUBJECT DOES NOT PULL THE CHEST RESTRAINT TIGHT. HE ALLOWS HIS BODY FREEDOM OF MOVEMENT WITHIN THE RESTRAINTS.

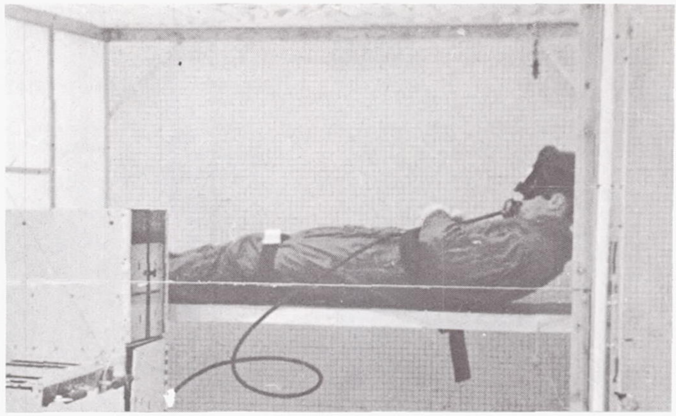
† ref. figs. 21, 23

TABLE XII.--PERFORMANCE ANALYSIS OF REST-SLEEP SUBTASK - CONTINUED

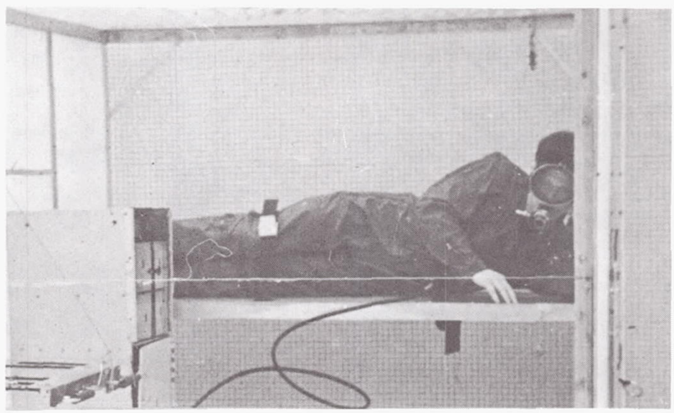
SUBTASK ELEMENT	DESCRIPTION	TIME SEC.	COMMENTS
REST IN BACK POSITION.	MAINTAINS THE BACK RESTING MODE UNTIL A RELAXED POSITION IS ATTAINED.	14	THE SUBJECT DOES NOT LIE FLAT ON THE BUNK, BUT ASSUMES A POSITION WITH HIS HEAD LEANING AGAINST THE BULKHEAD WALL, FIGURE 25.
READJUST RESTRAINTS AND TURN OVER.	LOOSENS CHEST RESTRAINT, LEANS FORWARD, AND LOOSENS THIGH RESTRAINT. TURNS OVER IN FACE-DOWN POSITION.	11	SUBJECT VARIES FROM CHECKLIST PROCEDURE HERE. HE NOTES THAT THERE IS NO NEED TO RELEASE CHEST RESTRAINT TO LOOSEN THIGH RESTRAINT.
REST IN FACE-DOWN POSITION.	MAINTAINS THE FACE-DOWN RESTING MODE UNTIL A RELAXED POSITION IS ATTAINED	5	
READJUST RESTRAINTS AND TURN OVER.	LOOSENS CHEST RESTRAINT, LEANS FORWARD, AND LOOSENS THIGH RESTRAINT. TURNS OVER TO SIDE POSITION.	5	SUBJECT NEGLECTS TO LOOSEN RESTRAINTS. HE NOTES THAT THIS IS NOT NECESSARY TO CHANGE POSITIONS BECAUSE HE HAS NOT TIGHTENED THEM SUFFICIENTLY TO RESTRICT MOVEMENTS.
REST IN SIDE POSITION.	MAINTAINS THE SIDE RESTING MODE UNTIL A RELAXED POSITION IS ATTAINED.	7	
REMOVE CHEST RESTRAINT.	RELEASES BELT RESTRAINT OVER CHEST AND ASSUMES A SITTING POSITION ON BUNK.	3	
REMOVE THIGH RESTRAINT.	RELEASE BELT RESTRAINT OVER THIGHS AND SWING LEGS OUT OVER SIDE OF BUNK.	7	SUBJECT PAUSES TO READ CHECKLIST ON BULKHEAD AFTER RELEASING RESTRAINTS: 8 seconds.

TABLE XII.--PERFORMANCE ANALYSIS OF REST-SLEEF SUBTASK - CONTINUED

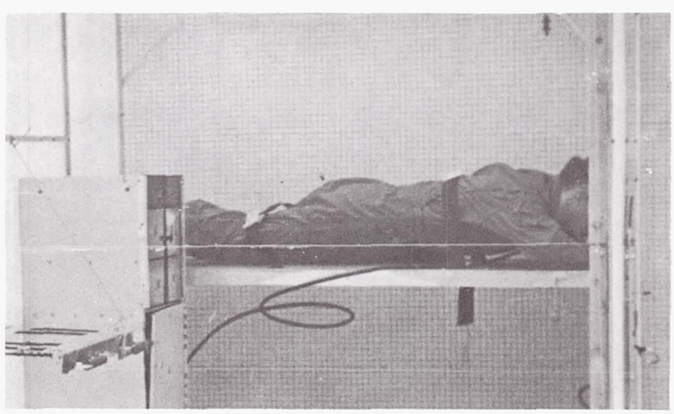
SUBTASK ELEMENT	DESCRIPTION	TIME SEC.	DESCRIPTION
DISMOUNT BUNK.	MANEUVERS BODY FROM SITTING POSITION ON BUNK TO STANDING POSITION ON COMPARTMENT FLOOR.	16	
READJUST RESTRAINTS.	REPOSITIONS BELT RESTRAINTS IN STOWED POSITION ON BUNK.	11	SUBJECT USES ONLY HANDHOLDS ON BELTS AS RESTRAINT FOR THIS SUBTASK ELEMENT.
DON WRS.	PLACES WEIGHTLESS RESTRAINT SANDALS ON FEET AND ASSUMES STANDING POSITION ON VELCRO FLOOR PAD.	16	SUBJECT FLOATS FREE IN CENTER OF COMPARTMENT WHILE DONNING WRS.



FACE UP



SIDE



FACE DOWN

FIGURE 20 - BASIC RESTING POSITIONS

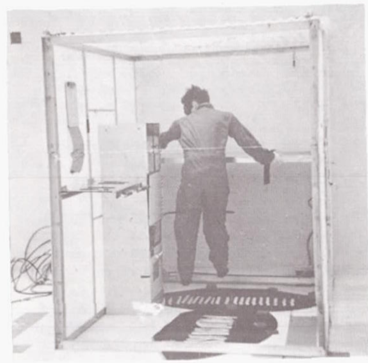
easily removed both sandals. The subject mounted the bunk by applying slight forces with his hands to guide his body into position, Figure 21d. He used the loosened chest and thigh restraints as handholds to maneuver his body. He moved from a standing position in front of the bunk, to a sitting position on the bunk with his legs over the side, to a sitting position with his legs on the bunk. He then attached the thigh restraint and positioned his body in a resting position on his back, Figure 21e. At this point he attached the chest restraint and assumed his resting evaluation position.

The subject rested on his back position, Figure 21f. It appeared as if the subject was not completely flat on the bunk but in a position with his head on an inclined plane. Actually, the subject was using the bulkhead wall to rest his head against while the trunk of his body lay flat on the bunk surface. When performing the 1G evaluation of this same task, the effects of gravity were immediately obvious. In the 1G simulation, the subject assumed a flat position on the bunk with his head in the horizontal plane of his body. In the zero gravity position, the subject, not having to worry about the weight of his head, comfortably assumed a position with his head on approximately a 30 degree angle with respect to his horizontal body position. Figure 22 shows the comparison of the back resting positions for zero and one gravity conditions. At this point the subject deviated from the checklist procedure which called for assuming a sitting position after releasing the chest restraint and then readjusting the thigh restraint for the side position evaluation. The subject noted during the subtask that it was not necessary for him to release the chest restraint completely to vary the thigh restraint. After completing the back position evaluation, he simply leaned forward to loosen his thigh restraint, Figure 23a. The subject then turned face down and rested in the face-down position, Figure 23b. The subject next turned to his side position without making any restraint adjustments and assumed this side resting position, Figure 23c. This was also a variation from his checklist which called for turning over and assuming the sitting position for making restraint adjustments prior to assuming the side rest position.

The subject's head was at approximately a 30 degree angle with respect to his horizontal body. He used his arm to rest his head on in this position, Figure 23d. From this position the subject released the chest restraint, assumed a sitting position, released the thigh restraint, and then dismounted the bunk. As he moved out of the bunk he resecured his chest and thigh restraints in the deployed position. The subject completed the task by donning his weightless restraint sandals which had been velcroed to the floor pads. At this point the task ended.

During the resting position evaluations, the subject was asked to maintain the face-down, side, or back position until he felt that

A



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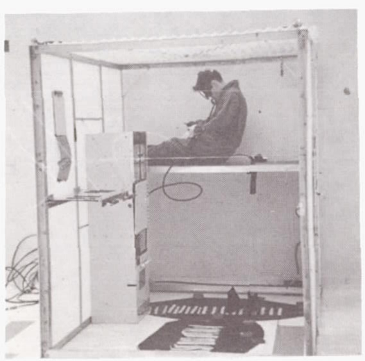

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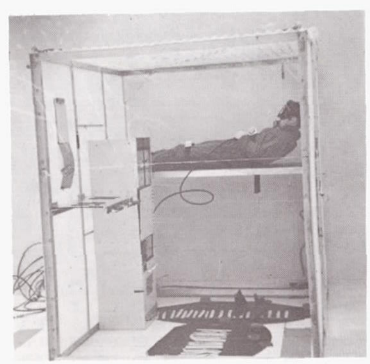
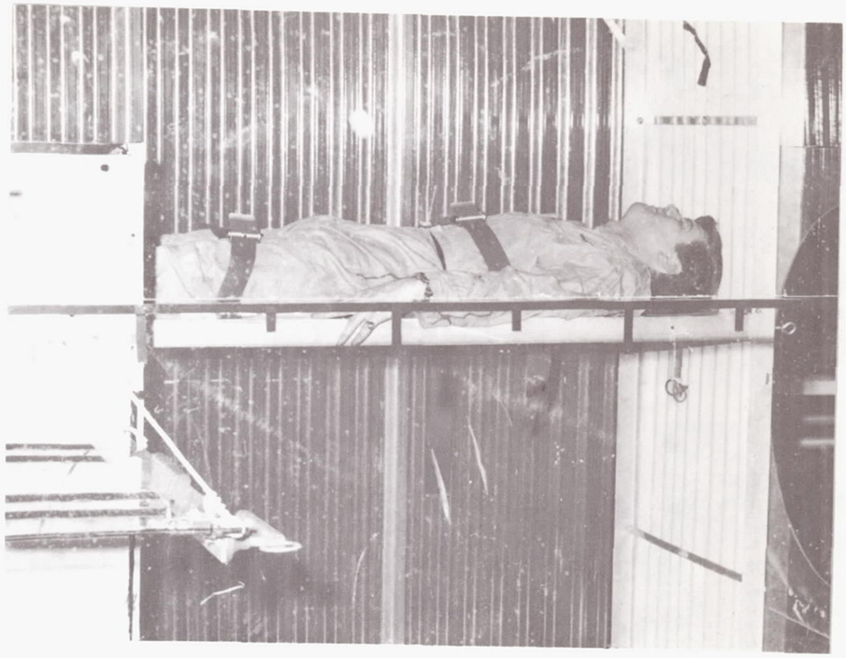
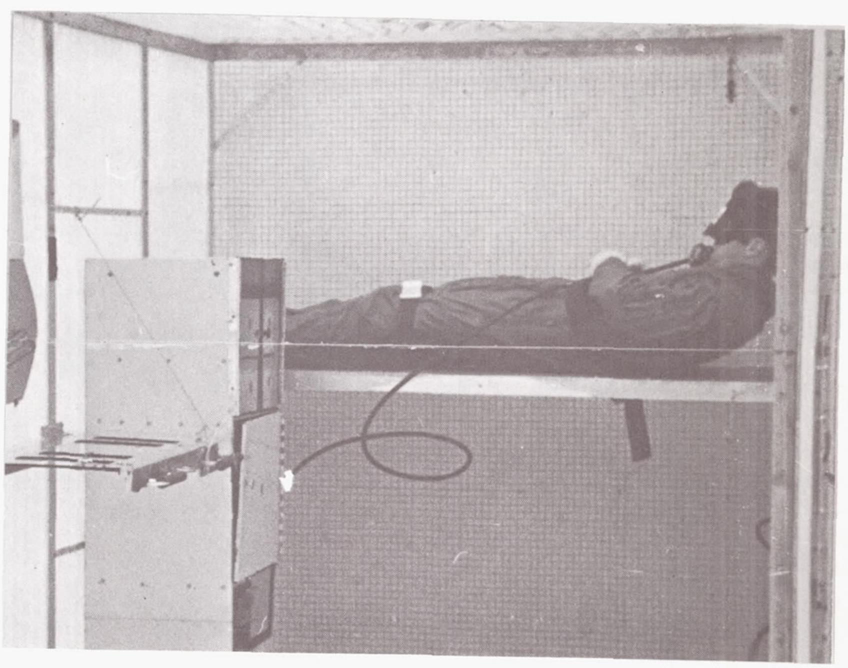


F

FIGURE 21 - SEQUENCE OF RESI-SLEEP SUBTASK (A)

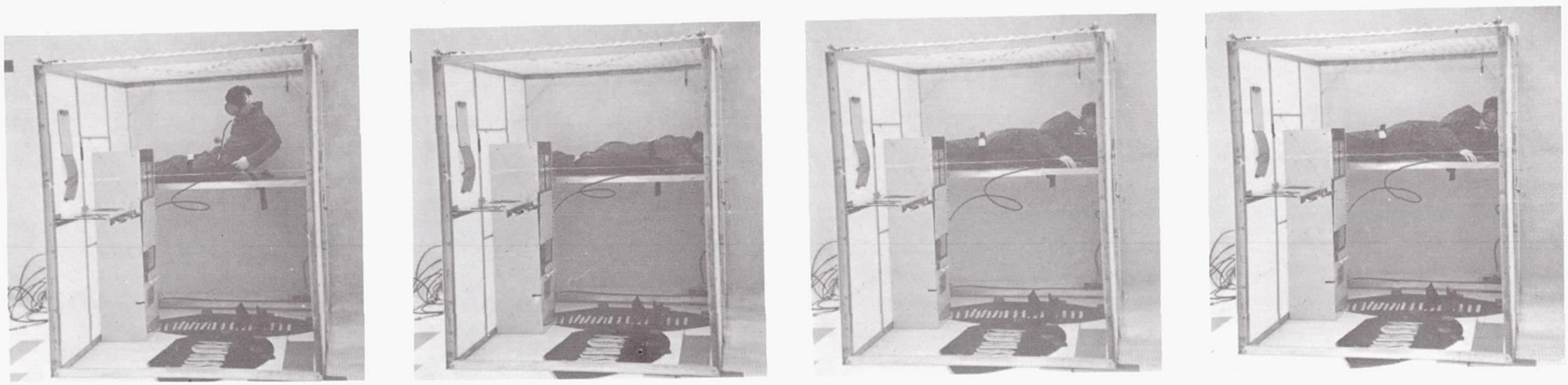


ONE GRAVITY



SIMULATED ZERO GRAVITY

FIGURE 22 - COMPARISON OF RESTING POSITIONS



A B C D

FIGURE 23 - SEQUENCE OF REST-SLEEP SUBTASK (B)

he was comfortable. If he did not feel comfortable, he was requested to make minor changes in his position until he could find a comfortable, relaxed attitude mode.

It is apparent that the subject had no trouble relaxing in any of the positions. The subject did comment that he preferred the resting on back position. He also commented that the chest and thigh restraints proved very adequate for resting in any of the three positions. He preferred to leave the restraints fairly loose across the body so positioning could be varied without constant attention to the restraints. It has been concluded from analysis of the film sequences that the six-foot bunk and compartment width was not adequate for the 5 ft 10 in. subject. It is also concluded that normal space requirements in one gravity conditions should dictate the sleeping unit requirements for zero gravity conditions. The dressing area, however, could be smaller in the 0G mode than in the 1G mode. Mounting devices for upper bunk positions are definitely not needed in zero gravity although a handrail along the horizontal edge of the bunk does aid in overall positioning.

Food handling: The food handling subtask was performed in the 84" x 84" x 72" compartment configuration. The configuration included a work table unit which folded into a stowed position against the bulkhead. To deploy the table unit, the subject released the velcro locking tabs, folded the unit into the deployed position, and locked the table into position with a positive locking mechanism. Adjacent to the table was the compartment storage unit (CSU). The unit was fixed to the 84" x 84" wall. The CSU dimensions were 18.0 inches wide and 15.0 inches deep. The height was 60.0 inches from the compartment floor.

The results of preliminary evaluations on the food handling subtask indicated that the velcro foot restraint and locomotion aid system and the handhold restraint and locomotion aid system were very adequate for performance of this task. The subject's dress was a standard flight suit and the velcro sandals.

The food handling subtask was designed to simulate the general performance of a crew member preparing a typical food menu for eating at a position other than the preparation area. The crew member's task was to unstow a personnel food tray in which he subsequently inserted the proper amounts of food and liquid called out in the diet menu for that particular day. After inserting the proper food packets into the personnel food units, the crew member loaded the personnel food unit into a food transfer unit capable of containing a number of the personnel food units. Upon completion of this task, the crew member transferred the food transfer unit to various parts of the spacecraft or space station and served the individual personnel food units to the crew members at their particular stations or at a single station dining area. The general concept considered the fact that food was stored in packet forms and these packets were stored in canisters in bulk amounts that

were easily accessible for daily food preparation. Food packets were of a paste type and a powder type to be mixed with water from a water injector gun. A personnel water unit, similar to an infant's plastic nursing bottle, was provided for drinking. This unit was filled from the water injector gun and the unit then mounted on the personnel food unit to be transferred with the latter unit. The water injector gun was mounted on the side of the CSU and was considered part of the overall water system of the station. Figure 24 shows the equipment used in the food handling subtask; Table XIII presents the data analysis.

The subject staged on the velcro foot pads in front of the stowed work table to initiate the food handling subtask simulation, Figure 25a. From this starting position he deployed the table and locked it into position. A task checklist and diet menu combination stored in the CSU, compartment GH, served the dual purpose of cuing the subject on his task procedure and simulating a menu-of-the-day card. The subject removed this card from the CSU and installed it on a bulkhead receptacle in front and above the work table, Figure 25b.

The first step on the checklist called for unstowing canisters' No. 1 and 2 from the CSU, compartment A, and velcroing these canisters on the right side of the table, Figure 25c. Rectangular solid food cubes and elongated flexible food packets of premixed paste type food were contained in canisters' No. 1 and 2. The subject's next task was to remove the personnel food unit from the CSU, compartment C, Figure 25d. The subject used his left hand on the handholds provided along the leading edge of the work table and, with his right hand, opened the compartment door and removed each of the items previously noted. These maneuvers required no movement of his feet. Each item was removed by bending slightly at the knees and leaning sideways to reach into the cabinet. The subject released his handholds, when necessary, to transfer the personnel food unit to his left hand and he then velcroed the unit to the left side of the work table, Figure 25e.

Consulting the checklist on the wall, the subject removed the food cubes fron canister No. 1 and inserted the three cubes in the personnel food unit. The subject used the velcro foot restraints to maintain his position during this portion of the subtask and, as he did not move from his initial standing position, he required no locomotion aid, Figure 25f. The subject varied slightly from the subtask procedure at this point when he opened all three trays of the personnel food unit prior to inserting the first food cubes. The procedure called for opening one tray at a time and, as the food packets were inserted, closing this tray and opening the next. This variation did not affect the task and proved to be an adequate method for performing the task since the trays, when opened, did not come free of the personnel food unit but stopped in the full open position.

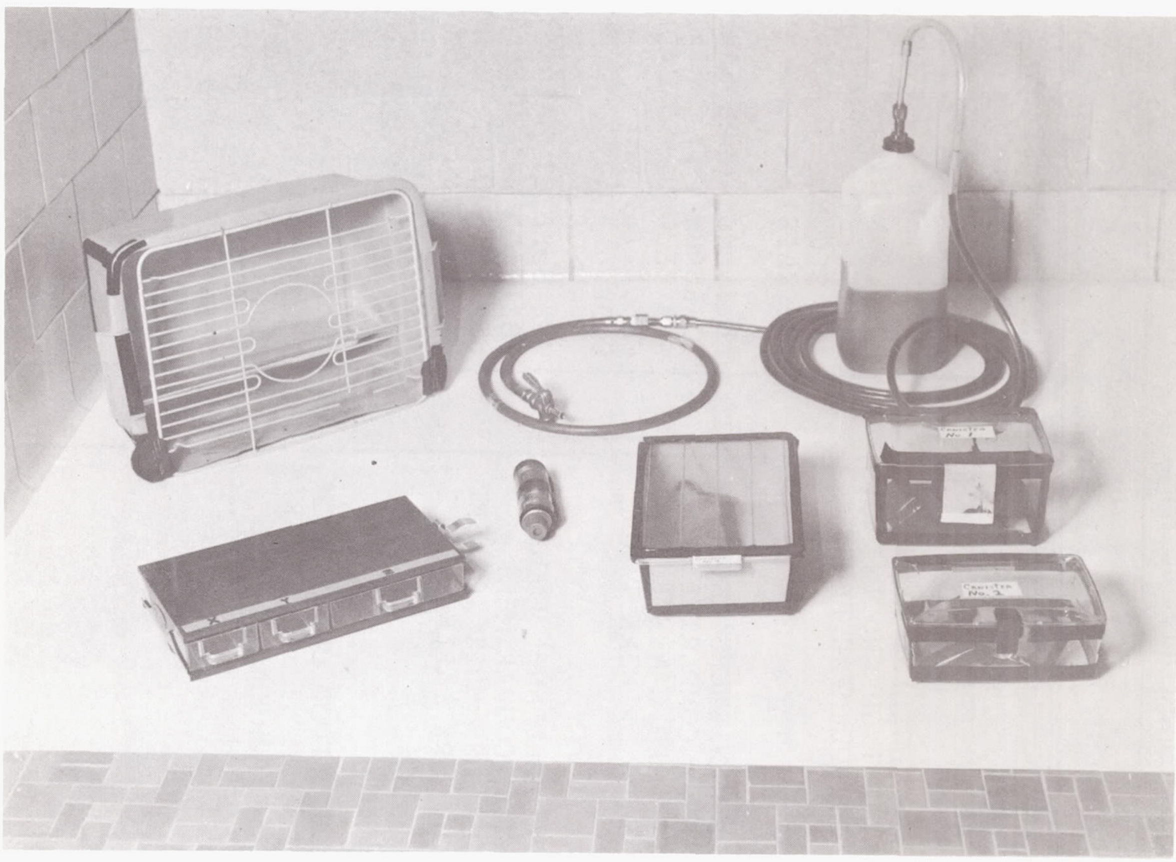


FIGURE 24 - FOOD HANDLING SUBTASK EQUIPMENT

TABLE XIII.--PERFORMANCE ANALYSIS OF FOOD HANDLING SUBTASK †

SUBTASK ELEMENT	DESCRIPTION	TIME SEC.	COMMENTS
UNSTOW WORK TABLE.	UNLATCHES STOWED TABLE, FOLDS DOWN, AND LOCKS IN DEPLOYED POSITION.	10	SUBJECT IS STANDING ON VELCRO FOOT RESTRAINTS.
UNSTOW CHECK-LIST.	REMOVES CHECKLIST FROM COMPARTMENT GH AND IN-SERTS ON BULKHEAD RECEP-TACLE.	13	SUBJECT USES HANDHOLDS ON TABLE TO POSITION HIS BODY WHEN REACHING FOR CHECKLIST. 4.0 SECONDS: READING INSTRUCTIONS ON CHECKLIST.
UNSTOW CANIS-TERS' NO. 1 AND 2.	REMOVES CANISTERS' NO. 1 AND 2 FROM COMPARTMENT A AND VELCROES CANISTERS TO RIGHT SIDE OF WORK TABLE.	15	IT IS NOT NECESSARY TO CHANGE POSITION TO REACH THE CANISTERS. 6.0 SECONDS: READING INSTRUCTIONS ON CHECKLIST WHILE CLOSING COMPARTMENT A DOOR.
UNSTOW PFU.	REMOVES PERSONNEL FOOD UNIT FROM COMPARTMENT C AND VELCROES UNIT TO LEFT SIDE OF WORK TABLE.	11	THE SUBJECT MAINTAINS HIS ORIGINAL POSITION AND USES THE VELCRO FOOT RE-STRAINTS ONLY TO HOLD THIS POSITION WHILE USING HIS HANDS TO WORK. 7.0 SECONDS: READING INSTRUCTIONS ON CHECKLIST WHILE CLOSE COMPARTMENT C.
LOAD PFU TRAY NO. x.	REMOVES 3 FOOD CUBES FROM CANISTER NO. 1 AND INSERTS CUBES IN PERSONNEL FOOD UNIT TRAY NO. x.	19	SUBJECT DOES NOT CLOSE CANISTER LID UNTIL ALL 3 FOOD CUBES ARE INSERTED IN FOOD TRAY. USING RIGHT HAND, SUBJECT REMOVES ALL 3 FOOD CUBES AT ONE TIME. USING LEFT HAND, HE OPENS AND CLOSES FOOD TRAY. HE MAINTAINS HIS POSITION USING VELCRO FOOT RESTRAINTS ONLY.

† ref. fig. 25

TABLE XIII --PERFORMANCE ANALYSIS OF FOOD HANDLING SUBTASK - CONTINUED

SUBTASK ELEMENT	DESCRIPTION	TIME SEC.	COMMENTS
LOAD PFU TRAY NO. y.	REMOVES 3 FOOD PACKETS FROM CANISTER NO. 2 AND INSERTS PACKETS IN PERSONNEL FOOD UNIT TRAY NO. y.	22	SUBJECT CONTINUES TO USE HIS VELCRO FOOT RESTRAINTS ONLY WHILE USING HIS HANDS TO WORK AT THE TABLE. 5.0 SECONDS: READING INSTRUCTIONS ON CHECKLIST.
RESTOW CANISTER NO. 2.	OPENS COMPARTMENT A. RESTOWS CANISTER NO. 2 IN COMPARTMENT A.	7	
RESTOW CANISTER NO. 1.	RESTOWS CANISTER NO. 1 IN COMPARTMENT A.	7	SUBJECT CLOSES COMPARTMENT DOOR WHILE READING CHECKLIST INSTRUCTIONS FOR NEXT TASK PROCEDURE. 10.0 SECONDS: READING INSTRUCTIONS ON CHECKLIST WHILE CLOSING COMPARTMENT A DOOR.
UNSTOW CANISTER NO. 3.	OPENS COMPARTMENT E. REMOVES CANISTER NO. 3 FROM COMPARTMENT AND VELCROES CANISTER TO RIGHT SIDE OF WORK TABLE.	17	SUBJECT DOES NOT APPEAR TO BE MAINTAINING ANY FIXED RESTRAINT POSITION HERE. HIS FEET ARE LIGHTLY VELCROED BY ONLY SMALL POINTS OF CONTACT TO THE FLOOR.
REMOVE DEHYDRATED FOOD PACKET.	OPENS CANISTER NO. 3, REMOVES 1 DEHYDRATED FOOD PACKET, AND CLOSES CANISTER.	8	
ADD WATER TO DEHYDRATED FOOD PACKET.	UNSTOWS WATER INJECTOR GUN FROM HOLDER ON CSU. INJECTS 5 cc WATER TO FOOD PACKET. RESTOWS INJECTOR GUN ON CSU.	31	SLIGHT SPILLAGE OF THE FLUID IS EVIDENT. THIS WAS DUE TO A FAULTY ONE-WAY VALVE AND NOT TO THE SIMULATED ENVIRONMENT.

TABLE XIII.--PERFORMANCE ANALYSIS OF FOOD HANDLING SUBTASK - CONTINUED

SUBTASK ELEMENT	DESCRIPTION	TIME SEC.	COMMENTS
MIX POWDER WATER PACKET.	KNEAD FOOD PACKET UNTIL CONTENTS ARE THOROUGHLY MIXED.	18	
LOAD PFU TRAY NO. z.	OPENS PERSONNEL FOOD UNIT TRAY NO. z. INSERTS POWDER WATER FOOD PACKET. CLOSES TRAY NO. z.	4	SUBJECT APPEARS AGAIN TO BE FLOATING FREE OF THE RESTRAINT SYSTEM OR, AT MOST, MAINTAINING A LIGHT CONTACT ON THE VELCRO FOOT RESTRAINTS WITH ONLY A SMALL AMOUNT OF SANDAL SURFACE AREA. 8.0 SECONDS: READING INSTRUCTIONS ON CHECKLIST.
RESTOW CANISTER NO. 3.	OPENS COMPARTMENT E. DETACHES CANISTER NO. 3 FROM WORK TABLE AND REPLACES CANISTER IN COMPARTMENT. CLOSES COMPARTMENT DOOR.	12	SUBJECT'S POSITION IS 2.9 FEET FROM THE BULKHEAD CONTAINING THE WORK TABLE. STANDING IN THIS POSITION ON THE VELCRO FOOT PAD, THE SUBJECT CAN COMFORTABLY REACH ALL POSITIONS ON THE WORK TABLE AND THE CSU. 3.0 SECONDS: READING INSTRUCTIONS ON CHECKLIST.
UNSTOW PWU.	OPENS COMPARTMENT B. REMOVES PERSONNEL WATER UNIT (PWU) AND VELCROES UNIT TO RIGHT SIDE OF WORK TABLE. CLOSES COMPARTMENT B.	10	
FILL PWU.	UNSTOWS WATER INJECTOR GUN FROM HOLDER ON CSU. INSERTS INJECTOR IN PERSONNEL WATER UNIT AND FILLS UNIT. REMOVES AND RESTOWS INJECTOR GUN.	18	3.0 SECONDS: SUBJECT PAUSES TO CLEAR HIS MASK OF WATER. 4.0 SECONDS: READING INSTRUCTIONS ON CHECKLIST.

TABLE XIII.--PERFORMANCE ANALYSIS OF FOOD HANDLING SUBTASK - CONTINUED

SUBTASK ELEMENT	DESCRIPTION	TIME SEC.	COMMENTS
ATTACH PWU TO PFU.	REMOVES PERSONNEL WATER UNIT FROM WORK TABLE, VELCROES AND INSERTS UNIT IN CLIP ON SIDE OF PERSONNEL FOOD UNIT.	7	SUBJECT USES VELCRO FOOT RESTRAINTS ONLY WHILE WORKING WITH HANDS.
UNSTOW FTU.	OPENS COMPARTMENT D. REMOVES FOOD TRANSFER UNIT (FTU) AND VELCROES UNIT TO RIGHT SIDE OF WORK TABLE. CLOSES COMPARTMENT D.	18	SUBJECT USES RIGHT HANDHOLD TO AID IN BENDING HIS BODY DOWN TO REACH AND REMOVE THE FTU IN COMPARTMENT D.
INSERT PFU INTO FTU.	OPENS FOOD TRANSFER UNIT (FTU). REMOVES PERSONNEL FOOD UNIT FROM LEFT SIDE OF WORK TABLE AND INSERTS UNIT IN BOTTOM RACK OF FTU. CLOSES FOOD TRANSFER UNIT AND LOCKS.	29	
RESTOWS CHECKLIST.	REMOVES CHECKLIST FROM BULKHEAD RECEPTACLE AND RESTOWS IN COMPARTMENT GH OF CSU.	11	SUBJECT AGAIN USES RIGHT HANDHOLD TO AID IN POSITIONING HIS BODY WHEN REACHING FOR THE CHECKLIST (RIGHT HAND ON HANDHOLD). HE USES HIS LEFT HAND ON RIGHT HANDHOLD WHEN STOWING THE CHECKLIST.

After closing the first tray, the subject opened canister No. 2 and removed three food packets as called out on the bulkhead diet menu. The food packets contained a ready-mixed food paste to be inserted in tray No. 2 of the personnel food unit. The subject closed the food unit tray No. 2 and proceeded to replace food canisters' No. 1 and 2 in the CSU, Figure 25g. The subject commented that the task, to this point, was very simple and required no restraints. He noted that his foot restraints and handholds were only marginally useful and that he did not consider this task to be a precision operation. Again the subject did not require the use of his locomotion aids but maintained a fixed position, bending at the knees and leaning, to stow the canisters, Figure 25h.

The subject consulted his checklist and unstowed canister No. 3 from compartment E of the CSU. He then secured this canister to the right side of the work table. It was seen in the film sequences of this task that the subject exerted little force in securing the canisters to the table. When securing canister No. 3, the subject's feet were not securely velcroed to the floor. Nevertheless, when placing the canister on the work table, very little body reaction was visible, Figure 25i.

Opening canister No. 3, the subject removed one dehydrated food packet as called out on the diet menu. Following checklist instructions, the subject transferred the packet to his left hand and removed the water injector gun from its mount on the side of the CSU. He then inserted the gun in the injector slot of the food packet and added 5 cu cm of water to the food packet. A slight spillage of the colored fluid was noted during this performance, Figure 25j. The subject commented later that this was due to a faulty valve in the food packet and was not a result of the zero gravity environment. After removing the injector from the packet, the subject replaced the gun on the CSU mount. He kneaded the contents with his fingers until they were thoroughly mixed. He then inserted the food packet in the third compartment of the personnel food unit and closed this last food unit tray. During this portion of the subtask the subject allowed himself to float free of his velcro foot restraints, Figure 25k. During the debriefing the subject noted that he was aware of this fact and that he did so only because he found no need for restraints to perform this operation. He also noted that for an extremely short duration maneuver of this type, when both hands are occupied, the velcro shoes were adequate to maintain body position.

A center line, measured vertically through the subject's body, placed his position 2.9 feet from the bulkhead wall while standing on the velcro foot pads. This was also approximately the center line of the velcro foot pad. The subject had positioned the velcro foot pads in the most comfortable position for this subtask during preliminary runs. Standing in this position he could comfortably reach all portions of the CSU and all positions on the table and

the bulkhead receptacle unit, Figure 25l. The subject maintained this position on the velcro throughout the subtask, except for the few seconds previously noted when he allowed himself to drift off the velcro floor pad.

After restowing canister No. 3, the subject unstowed the personnel water unit, compartment B. The water unit, Figure 24, was then velcroed to the right side of the work table, Figure 25m. The subject unstowed the water injector gun from its mount on the CSU and inserted the gun into the personnel water unit. After filling the unit with water, the subject removed and restowed the gun and then attached the personnel water unit to the slip on the personnel food unit.

Throughout these maneuvers, the subject maintained his original position on the velcro foot pads. Grasping the right handhold on the table with his left hand and bending at the knees, the subject leaned down toward compartment D, at the bottom of the CSU, Figure 25n. He then opened the stowage unit and unstowed the food transfer unit with his right hand. The spring-loaded door closed by itself as he pulled the food transfer unit out of the compartment. With the aid of the handhold he then stood erect and secured the food transfer unit to the right side of the work table. The subject noted in previous runs that, when bending in this position with the foot restraints only, he found it hard to maintain his stance on the velcro restraints. This difficulty was one failure of the velcro foot restraint system, i.e., it does not allow placement of the body in any position without some other restraint or positioning aid. The answer to this problem was the handhold configuration which allowed the subject a firmly attached aid to move his body into the desired position. Since the handholds themselves have been shown to be adequate for this type of positioning, the question arises why use the velcro foot pads at all. From the preliminary restraint and locomotion aid evaluation tasks, it was noticed that the foot restraints, although not adequate for gross body movements, do allow a light attach point that is easily attained without waste of time or effort. In the case of positioning at the table, the velcro permits the subject to relax and prevents his feet from sliding under the table due to minor torquing forces initiated by the upper portion of his body. As previously noted, they were also adequate for stationary tasks requiring only small forces and lasting for short time durations.

The subject next opened the food transfer unit door and, with his left hand, detached the personnel food unit from the table and inserted the food unit in the food transfer unit, bottom rack, Figure 25o. After verifying that the food unit was completely in the transfer unit rack, the subject closed the food transfer unit door and activated the door locking mechanism.

The final step of the subtask was to remove the checklist from the receptacle and restow this list in compartment GII. With the aid of

the right handhold, the subject stretched over the table and, with his left hand, removed the checklist, Figure 25p. With the checklist in his left hand, the subject used the right handhold aid to bend his body into position near the CSU, in order to restow the checklist. The subtask ended at this point.

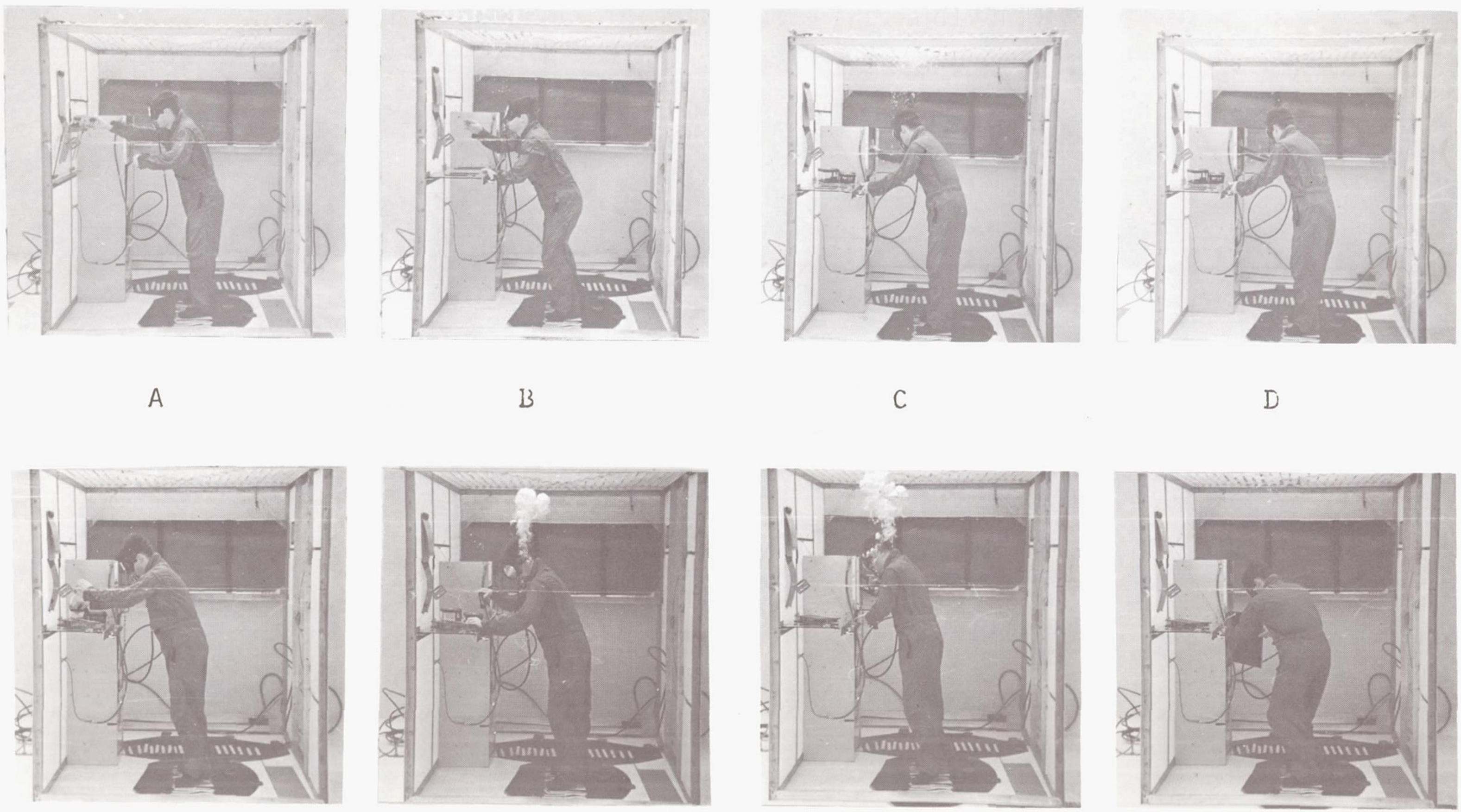
The analysis of the food handling subtask showed that the restraints and locomotion aids, velcro sandals and handrails, were very adequate systems for the performance of this subtask. In most portions of the subtask either of the two restraint systems were adequate without the other and, in many cases, the subtask elements could be performed without any restraint system. From preliminary runs, however, and from analysis of the final subtask run, it seems that the handholds and velcro sandal combination allows ease of movement and precision work without sacrificing time on preparation and positioning of elaborate restraint and locomotion aid systems.

The food canister and the personnel food unit also appeared to function adequately. The subject commented that he encountered no difficulty at any point in handling the three various canister sizes, nor did he encounter any trouble in handling the food packets or food cubes.

The food transfer unit, being the largest item handled during this task, was scrutinized closely in the film analysis. There seemed to be no problem in handling this item. The subject verified this in his debriefing comments and noted that one hand was sufficient to carry this unit, allowing the other hand free for movement using handholds or handrail aids. He also noted that he preferred a handhold on the food transfer unit to holding the unit under his arm. The food transfer unit was provided with a grid type door which, in effect, provided infinite handhold positions on this unit. The subject commented that he found this to be an ideal system for carrying the food unit.

The velcro strips on the work table and CSU shelves proved adequate for securing small items to the work table and in the compartment stowage unit. The 84" x 84" x 72" compartment space proved sufficient to accommodate all portions of the food handling subtask.

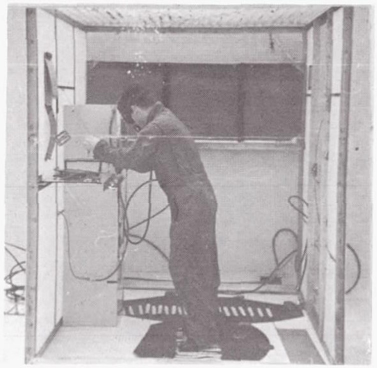
Exercise: The problems of body conditioning within the spacecraft during extended space missions were investigated by performing a standard set of exercises modified for simulated weightless conditions by means of various restraints and locomotion aids. The exercise subtask was performed in an 84" x 84" x 72" compartment configuration. The compartment stowage unit (CSU) was positioned the same as in the food handling subtask within the compartment. A work table maintained in the deployed position with handhold positions and tether attachment rings was also located similarly to the food handling subtask. A second waist tether attachment point was located on the bulkhead, opposite the table unit and adjacent to the hatch. In the preliminary runs this positioning of tether attachment points proved to be optimum for the exercise subtask. The



A B C D

E F G H

FIGURE 25 - SEQUENCE OF FOOD HANDLING SUBTASK



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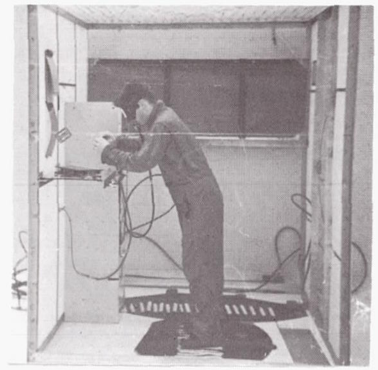

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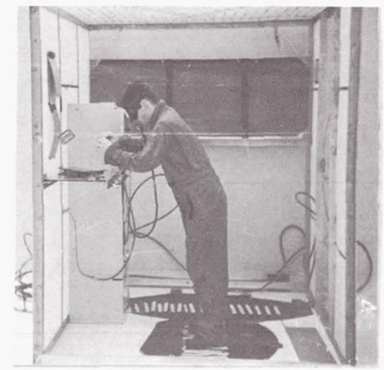

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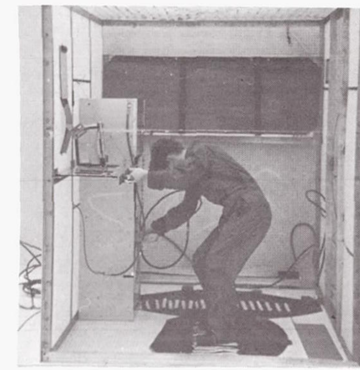

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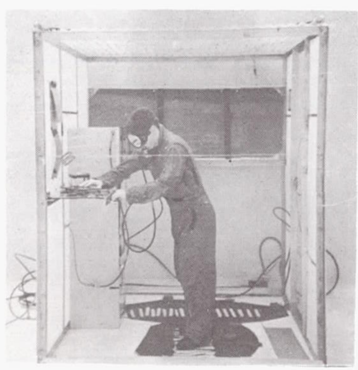

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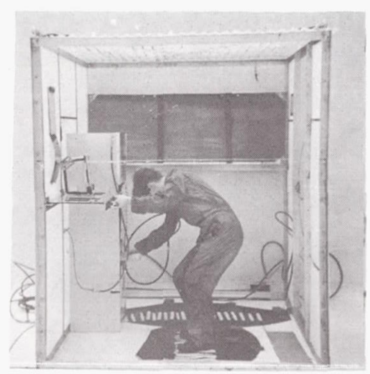

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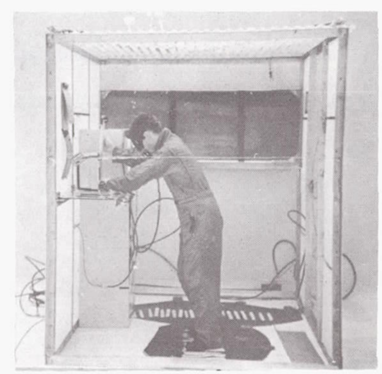

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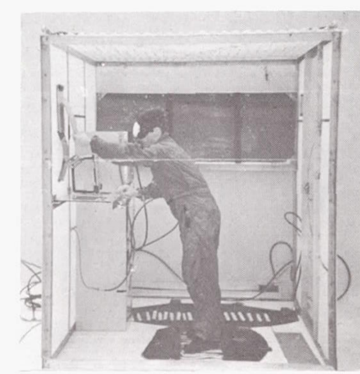

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FIGURE 25 - SEQUENCE OF FOOD HANDLING SUBTASK_CONTINUED

subject's dress for the exercise subtask was the standard flight suit with velcro sandals. Two adjustable waist tethers were attached, with quick release attachments on both ends, to the subject's reenforced waist belt. Table XIV presents the performance analysis for the exercise subtask and is related to the following description.

The subject began the subtask staged on the velcro foot pads facing the work table and CSU. Using the handhold provided on the work table, the subject leaned down and unstowed the exercise-of-the-day checklist from compartment GH of the CSU, Figure 26a. The subject stood erect and inserted the checklist in the bulkhead receptacle above the work table. He turned 90 degrees to his left, standing approximately in the center of the compartment width. For this slight repositioning maneuver the subject used both the handholds and the velcro foot restraints, Figure 26b.

In this position the subject attached his right waist tether to the bulkhead tether ring on the opposite side of the compartment, Figure 26c. The subject then tightened both waist tethers so that he was, in effect, suspended in the center of the compartment. In this position, with the tethers taut, the subject could touch his toes to the velcro floor pads, but he could not maintain a foothold on this velcro, Figure 26d. Rotating his body 90 degrees, the subject could place his feet on the front wall of the compartment and, by pressing against the wall and using the tethers as restraints, he could maintain a fixed stance in this position, Figure 26e.

The subject slackened his waist tethers slightly and gained a standing position on the velcro foot pads. From this position he began his warm-up schedule consisting of 3 exercises. The first exercise performed, the elevator, was a stretching exercise. The exercise action was to raise the body up and down on the toes. It was not necessary to maintain a foothold since extension of the toes was only a stretching performance and not one of lifting the body on the toes. The subject thus allowed his feet to float free of the velcro foot pads and relied entirely on his waist tethers to maintain his position. In the debriefing he commented that this exercise could be improved by lowering the tether attachment positions approximately 12 inches. In this position, with both waist tethers tightened down, the subject could stand firmly on the velcro floor pad and exercise against the waist tethers, transforming the exercise into an isometric.

The subject next detached his left waist tether from the bulkhead attachment ring. This allowed him to return to his position facing the work table, by pulling on his right waist tether, Figure 26f. From this position the subject reached down and opened compartment W of the CSU. He unstowed the modified isometric exerciser, Figure 27, from compartment W and closed the compartment door. The subject realized, at this point, that he had performed

TABLE XIV.--PERFORMANCE ANALYSIS OF EXERCISE SUBTASK †

SUBTASK ELEMENT	DESCRIPTION	TIME SEC.	COMMENTS
UNSTOW CHECK-LIST.	OPENS COMPARTMENT GH. REMOVES EXERCISE CHECKLIST AND INSERTS CHECKLIST IN BULKHEAD RECEPTACLE.	16	3.0 SECONDS: SUBJECT ADJUSTS FACE MASK. 4.0 SECONDS: SUBJECT READS EXERCISE INSTRUCTIONS ON CHECKLIST.
ATTACH WAIST TETHERS.	ATTACHES RIGHT WAIST TETHER TO WORK TABLE TETHER RING. ATTACHES LEFT WAIST TETHER TO OPPOSITE BULKHEAD TETHER RING.	10	
ADJUST WAIST TETHERS.	TIGHTENS LEFT AND RIGHT WAIST TETHERS UNTIL BODY IS SUSPENDED ABOVE COM-PARTMENT FLOOR ON TETHERS ONLY.	13	
PERFORM WARM-UP EXERCISE NO. 1.	PERFORMS WARMUP ELEVATOR EXERCISE BY EXTENDING ARMS AND TOES FULL LENGTH AND STRETCHING APPROPI-ATE MUSCLES. REPEAT EX-ERCISE 3 TIMES.	21	SUBJECT NOTES THAT EXERCISE WOULD BE MORE MEANINGFUL IF HE COULD HAVE PUSHED AGAINST A FIXED OBJECT IN AN ISOMETRIC FASHION.
DETACH LEFT WAIST TETHER.	DISCONNECTS LEFT WAIST TETHER AND RETURNS TO POSITION FACING WORK TABLE AND STOWAGE CABI-NET.	4	SUBJECT READS NEXT STEP ON CHECKLIST WHILE DISCONNECTING HIS WAIST TETHER.
UNSTOW MODI-FIED ISOMET-RIC EXERCISER.	OPENS COMPARTMENT I OF THE CSU AND REMOVES THE EXERCISER. VELCROES	10	SUBJECT PERFORMS THE STEP OUT OF ORDER. THE CHECKLIST CALLS FOR PER-FORMANCE OF ALL WARMUP EXERCISES

† ref. figs. 26, 28

TABLE XIV.--PERFORMANCE ANALYSIS OF EXERCISE SUBTASK - CONTINUED

SUBTASK ELEMENT	DESCRIPTION	TIME SEC.	COMMENTS
	EXERCISER TO WORK TABLE.		PRIOR TO UNSTOWING THE EXERCISER.
REATTACH LEFT WAIST TETHER.	TURNS 90° TO THE LEFT AND ATTACHES LEFT WAIST TETHER TO BULKHEAD ATTACHMENT RING.	16	SUBJECT REALIZES HE IS PERFORMING AN ELEMENT OUT OF ORDER AND CONSULTS THE CHECKLIST TO VERIFY HIS NEXT PROCEDURE.
PERFORM WARM-UP EXERCISE NO. 2.	PERFORMS WARMUP STRETCHER EXERCISE BY EXTENDING ARMS HORIZONTALLY IN FRONT OF BODY AND BENDING FORWARD, TOUCHING TOES AND RETURNING TO UPRIGHT POSITION. REPEATS EXERCISE 6 TIMES.	75	SUBJECT BEGINS EXERCISE SUSPENDED ON WAIST TETHERS. HE THEN MODIFIES HIS POSITION BY PLACING HIS FEET AGAINST THE FRONT BULKHEAD AND MAINTAINING THIS STANCE WITH FORCES EXERTED AGAINST THE WAIST TETHERS. 22.0 SECONDS: SUBJECT READS INSTRUCTIONS ON CHECKLIST.
READJUST WAIST TETHER.	LOOSENS WAIST TETHERS AND REGAINS STANDING POSITION ON VELCRO FLOOR PAD.	6	
PERFORM WARM-UP EXERCISE NO. 3.	PERFORMS WARMUP TWISTER EXERCISE BY BENDING FORWARD AT WAIST, TWISTING TO SIDE AND BACK AND TO SIDE AGAIN AND THEN RETURNING TO FORWARD POSITION. THIS ROTATING EXERCISE IS PERFORMED 5 TIMES TO THE LEFT AND 5 TIMES TO THE RIGHT.	47	SUBJECT BEGINS EXERCISE STANDING ON VELCRO FLOOR PAD. HE MODIFIES HIS POSITION BY TIGHTENING HIS WAIST TETHERS AND PLACING HIS FEET AGAINST THE FRONT BULKHEAD AS IN EXERCISE NO. 2. HE NOTES THAT THIS POSITION IS MORE STABLE FOR THIS TYPE OF EXERCISE. LARGE MAGNITUDE FORCES/MOTION DO NOT APPEAR TO BE TRANSMITTED TO MOCK-UP.

TABLE XIV.--PERFORMANCE ANALYSIS OF EXERCISE SUBTASK - CONTINUED

SUBTASK ELEMENT	DESCRIPTION	TIME SEC.	COMMENTS
PERFORM CONDITIONING EXERCISE NO. 1.	INSERTS FEET INTO MODIFIED ISOMETRIC EXERCISER. PERFORMS ISOMETRIC CONDITIONING ARM CURLS BY HOLDING LEGS IN THE EXTENDED POSITION, PULLING CURLS AGAINST THE EXERCISER, AND HOLDING CURLS FOR 6 SECONDS AT POINT OF MAXIMUM TENSION. REPEATS EXERCISE 5 TIMES.	110	SUBJECT HAS ALREADY UNSTOWED EXERCISER AS NOTED PREVIOUSLY. HE NOW RETRIEVES EXERCISER FROM UPPER CORNER OF COMPARTMENT ABOVE WORK TABLE WHERE IT HAS DRIFTED AFTER THE SUBJECT UNSUCCESSFULLY VELCROES IT TO THE WORK TABLE. SUBJECT PERFORMS THIS EXERCISE STANDING ON THE VELCRO FLOOR WITH HIS WAIST TETHERS SLACK.
READJUST WAIST TETHERS AND BODY POSITION.	TIGHTENS WAIST TETHERS AND POSITIONS FEET ON FRONT WALL.	15	SUBJECT READS CHECKLIST INSTRUCTIONS PRIOR TO TIGHTENING WAIST TETHERS.
PERFORM CONDITIONING EXERCISE NO. 2.	PERFORMS ISOMETRIC CONDITIONING LEG EXTENSIONS BY HOLDING ARMS IN RIGID CURL POSITION AND EXTENDING LEGS, HOLDING THE FULL LEG EXTENDED POSITION FOR 6 SECONDS AND SLOWLY BRINGING LEGS BACK TO TUCKED POSITION. REPEATS EXERCISE 5 TIMES.	35	SUBJECT PERFORMS EXERCISE SUSPENDED ON WAIST TETHERS ONLY. VERY LITTLE PERTURBATION OF THE MOCK-UP DURING EXERCISE.
DETACH WAIST TETHERS.	REMOVES RIGHT AND LEFT WAIST TETHERS FROM ATTACHMENT RINGS. MANEUVER INTO POSITION FACING WORK TABLE.	10	SUBJECT PUSHES OFF BULKHEAD WALL AND SOARS INTO POSITION IN FRONT OF TABLE.

TABLE XIV.--PERFORMANCE ANALYSIS OF EXERCISE SUBTASK - CONTINUED

SUBTASK ELEMENT	DESCRIPTION	TIME SEC.	COMMENTS
STOW EXERCISER	OPENS COMPARTMENT W. STOWS EXERCISER. CLOSES COMPARTMENT W.	7	SUBJECT USES NO RESTRAINTS EXCEPT HIS HANDHOLD ON DOOR OF COMPARTMENT W.
STOW CHECKLIST	REMOVES CHECKLIST FROM BULKHEAD RECEPTACLE AND STOWS IN COMPARTMENT GH.	30	SUBJECT USES HANDHOLDS ON WORK TABLE TO AID IN POSITIONING HIS BODY.

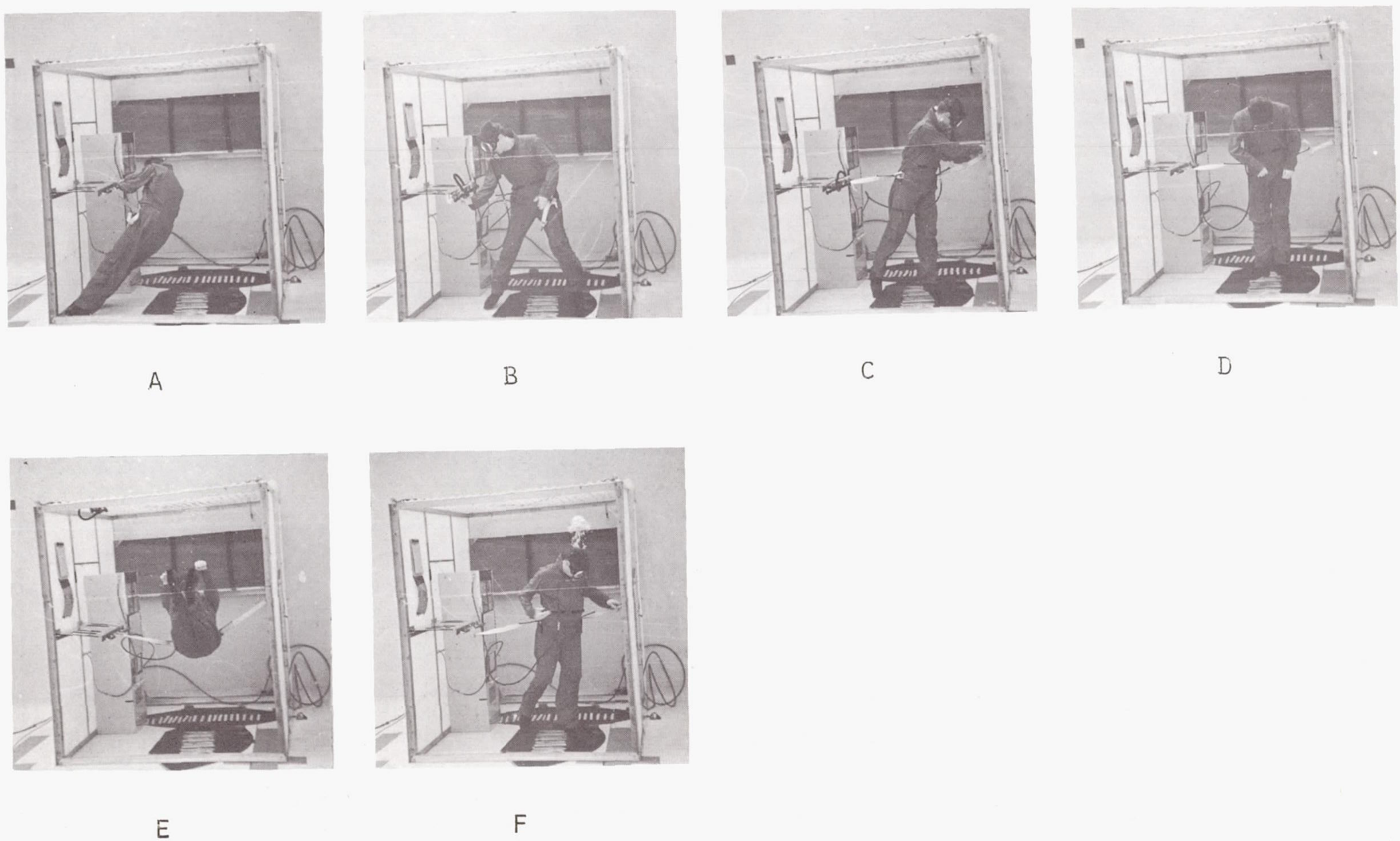


FIGURE 26 SEQUENCE OF EXERCISE SUBTASK (A)

FIGURE 27 - MODIFIED ISOMETRIC EXERCISER

the exercise unstowing procedure before he had completed his warm-up exercises. This was contrary to his checklist instructions. He velcroed the exerciser to the right side of the work table and consulted the checklist for his next exercise. After reading the checklist he turned 90 degrees to his left and reattached his left waist tether. He accomplished this maneuver by pushing free of the floor and using the handholds on the work table to position his body in the center of the compartment where he could reach the tether attachment position on the bulkhead, Figure 28a.

The subject tightened both tethers until he was suspended by the tethers in the center of the compartment, Figure 28b. In this position he performed the second warm-up exercise, the stretcher. The subject modified his position during the exercise by placing his feet on the front bulkhead and maintaining this position with pressure against the waist tethers. He noted in the debriefing that he preferred this fixed position over the suspended position, because the more stable position allowed him better control over his movements.

The subject loosened his waist tethers and regained his standing position on the velcro floor. He then began the third warm-up exercise. The third exercise, the twister, involved bending the upper portion of the body at the hips in a circular fashion to the forward, side, and back positions. After performing two complete movements of this exercise, the subject again modified his standing position. He tightened his waist tethers and placed his feet on the forward wall, Figure 28c. He commented in the debriefing that this position was the most stable and the best position for this type of exercise. The subject consulted his checklist for the next exercise. In the debriefing he noted that the checklist was not large enough to be read easily when he was tethered in the center of the compartment, Figure 28d.

The subject next retrieved the isometric exerciser from the upper corner of the compartment. When velcroing the exerciser to the work table earlier in the task, the subject had failed to properly secure the unit. The exerciser drifted off the table due to the small perturbations caused by the subject's movements against the waist tethers during the exercises.

In the standing position on the velcro floor pad, the subject inserted his feet in the stirrups of the exerciser, Figure 28e. He then began the first conditioning exercise, arm curls. By holding his legs in the extended position, the subject performed arm curls and held the maximum tension position for 6 seconds. He repeated this exercise 5 times, resting 4 seconds between curls. For the first time during this subtask, the subject allowed his feet to remain on the velcro floor throughout the exercise. He placed no tension on his waist tethers during the exercise and it appeared that he had no trouble maintaining his foothold on the velcro floor, Figure 28f.

For the final conditioning exercise, leg extensions, the subject tightened his waist tethers until he was suspended in the center of the compartment. He performed the second conditioning exercise by holding his arms in the curl position and extending his legs against the tension of the exerciser, Figure 28g. He maintained the full extended leg position for 6 seconds. He repeated this exercise 5 times, resting 4 seconds between each leg extension.

After completing the last exercise, the subject released his waist tethers and returned to a standing position in front of the work table. Using the handholds on the work table for body positioning, he stowed the exerciser and checklist in their appropriate compartments, Figure 28h.

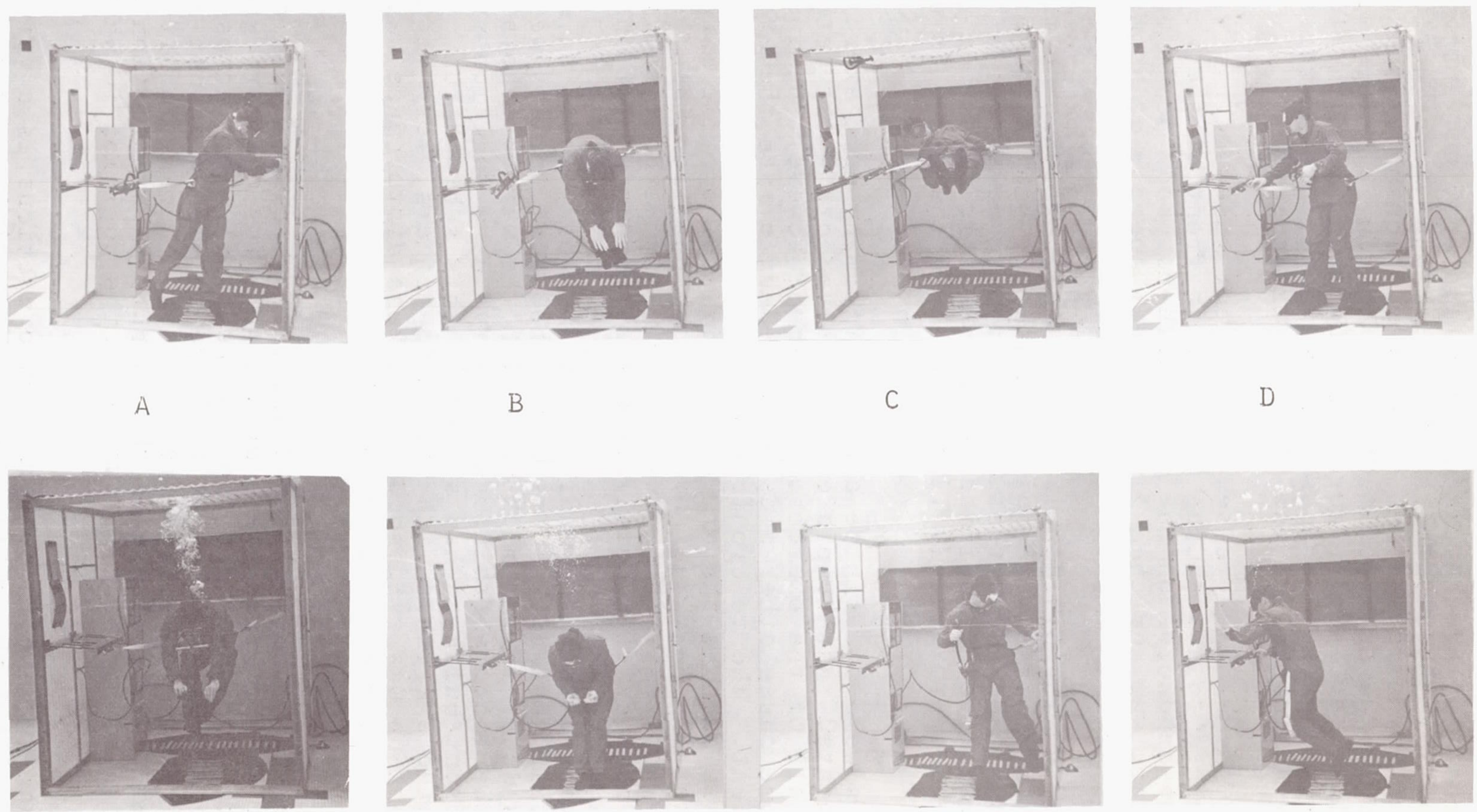
The subject noted during his debriefing that all exercises performed during this subtask were quite feasible in simulated zero gravity conditions. He added that the first warm-up exercise would be more effective if modified to an isometric by use of waist tethers positioned approximately 12 inches lower than in this mock-up configuration.

The waist tethers were a definite aid in performing most exercises. The subject commented that he preferred to have both waist tethers attached during all of the exercises performed; however, he indicated that in some cases other aids were needed to make the exercise more efficient. The velcro foot restraints served this purpose for exercises such as the arm curl modified isometric maneuver. In this exercise, a fixed and stable leg position was most important. The foot restraints provided this aid without sacrificing exercise efficiency with complicated restraint preparations.

The subject commented that the modifications in body position made during this subtask were not necessary if the waist tethers were placed 12 inches lower in the mock-up. With the waist tethers in this position, the foot restraints would serve as a position stabilizer as the front bulkhead had served in this subtask run. When performing the exercises with the waist tethers, very little motion of the mock-up was evidenced. Even less disturbance was seen when velcro foot restraint and waist tether combination was used.

The subject noted that the modified isometric exerciser used in this subtask was an excellent piece of hardware for the zero gravity environment. He added that the placement of velcro across the bottom of the apparatus, so that it could be secured when not in use or between exercises, was a definite asset. Because of its design, it vibrated readily with even the slightest perturbation and this vibration caused it to drift away from the position in which it was placed.

Hygiene: Personal hygiene in orbiting space stations is a very important problem. Since the water immersion technique precludes an



A B C D

E F G H

FIGURE 28 - SEQUENCE OF EXERCISE SUBTASK (B)

actual assessment of the hygienic efficiency of the proposed technique, tests were conducted to assess the feasibility of use of restraints and locomotion aids during a simulated hygiene task. The problems of personal hygiene, within the spacecraft during extended space missions, were investigated by demonstrating the cleansing of the entire body surface with a cleansing cloth in a simulated zero gravity environment. It was obvious during the preliminary runs that the hygiene subtask did not present a problem from the standpoint of restraints or locomotion aids. The subtask did not require gross movement from position to position or the use of elaborate restraint setups. The final run substantiated this observation. The handholds and the velcro foot pads were effective restraint and locomotion aids; however, in most cases, the subject required no external aids to efficiently perform this subtask.

Personal hygiene was performed in the 84" x 84" x 72" compartment configuration. The compartment stowage unit (CSU) was positioned within the compartment, in a manner similar to that employed during the food handling and exercise subtasks. A work table was maintained in the deployed position with handhold positions along its edge. The subject wore the full wet suit. A glove type cloth was used for the cleansing operation and was made of white nylon to contrast with the black wet suit configuration, Figure 29.

Table XV is the performance analysis for the hygiene subtask and is related to the following description. The subject began the hygiene subtask staged on the velcro foot pads facing the work table and CSU, Figure 30a. He used the handholds on the work table as a positioning aid as he leaned down to unstow the hygiene subtask checklist from compartment GH of the CSU. Pushing off the foot restraints with his toes, he drifted up to the bulkhead checklist receptacle and inserted the checklist, Figure 30b.

He opened the compartment of the CSU and removed the protective bag, containing one cloth, without the use of the handholds or foot restraints, Figure 30c. He removed the cloth from its protective bag and disposed of the bag in compartment W of the CSU, still remaining free of any restraints. The subject repositioned his body on the velcro foot restraints. He first allowed his body to drift over the foot pads and, when he was in position, he used the handholds to force his legs onto the velcro, Figure 30d.

The subject donned the glove on his right hand and began the task. As he performed this maneuver he automatically reached for the work table handhold and used this handhold periodically to stabilize his position, Figure 30e. He also maintained a light contact on the foot restraints; however, he employed this aid fewer times than the handholds. The subject removed the cloth from his right hand and donned it on his left hand. He repeated the task with his left hand. He again used the handhold on the left side of the work table to steady his position while performing the cleansing maneuver, Figure 30f.

FIGURE 29 - GLOVE CLEANSING CLOTH

TABLE XV.--PERFORMANCE ANALYSIS OF HYGIENE SUBTASK †

SUBTASK ELEMENT	DESCRIPTION	TIME SEC.	COMMENTS
UNSTOW CHECK-LIST.	OPENS COMPARTMENT. REMOVES HYGIENE CHECKLIST AND INSERTS ON BULKHEAD RE-CEPTACLE. CLOSES COMPART-MENT	17	SUBJECT IS STANDING FIRMLY ON VELCRO FOOT RESTRAINT PADS. HE USES THE RIGHT HANDHOLD ON THE WORK TABLE WITH HIS LEFT HAND TO AID IN POSITIONING HIS BODY WHEN BENDING TO REACH COM-PARTMENT
UNSTOW CLOTH	OPENS COMPARTMENT. REMOVES PROTECTIVE BAG CONTAINING ONE CLOTH GLOVE. CLOSES COMPARTMENT.	7	SUBJECT IS FREE OF VELCRO FOOT RE-STRAINT. HE USES COMPARTMENT DOOR AS A HANDHOLD.
REMOVE CLOTH	OPENS PROTECTIVE PLASTIC BAG, REMOVES CLOTH AND DISPOSES OF BAG	20	SUBJECT USES NO RESTRAINTS WHILE OPENING PROTECTIVE BAG OR WHEN DIS-POSING OF BAG IN COMPARTMENT. 8.0 SECONDS: SUBJECT REPOSITIONS BODY ON VELCRO FLOOR PADS AFTER DIS-POSING OF PLASTIC BAG. HE USES HAND-HOLDS ON WORK TABLE TO POSITION HIS FEET AGAINST THE VELCRO TO GAIN A STABLE POSITION. 3.0 SECONDS: SUBJECT READS CHECKLIST.
DON CLOTH	INSERTS RIGHT HAND IN CLOTH	23	SUBJECT USES VELCRO FOOT RESTRAINTS TO MAINTAIN POSITION WHILE DONNING CLOTH.
CLEANSE ALL BODY POSITIONS	TOUCHES ALL POSSIBLE BODY POSITIONS--LEFT ARM, LEFT SIDE, AND LEFT LEG. † ref. fig. 30	17	SUBJECT USES VELCRO FOOT RESTRAINTS TO MAINTAIN POSITION AND PERIODICALLY USES LEFT HANDHOLD TO STEADY HIS POSITION.

TABLE XV.--PERFORMANCE ANALYSIS OF HYGIENE SUBTASK - CONTINUED

SUBTASK ELEMENT	DESCRIPTION	TIME SEC.	COMMENTS
DON CLOTH	REMOVES CLOTH FROM RIGHT HAND AND INSERTS LEFT HAND IN CLOTH	26	SUBJECT DRIFTS FREE OF VELCRO FOOT RESTRAINTS WHILE DONNING CLOTH. HE REGAINS HIS FOOTHOLD WITH AID OF THE RIGHT HANDHOLD AND CONTINUES TO DON THE CLOTH
CLEANSE ALL BODY POSITIONS	TOUCHES ALL POSSIBLE BODY POSITIONS--RIGHT ARM, RIGHT SIDE, RIGHT LEG, BACK AND CHEST	18	SUBJECT USES LEFT HANDHOLD ON WORK TABLE AS MAIN RESTRAINT FOR THIS MAN-EUVER. OCCASIONALLY HIS FEET ENGAGE THE VELCRO FOOT RESTRAINTS
DISPOSE OF CLOTH	REMOVES CLOTH FROM HAND AND PLACES CLOTH IN WASTE COMPARTMENT	12	SUBJECT USES THE COMBINATION OF VEL-CRO FOOT RESTRAINTS AND THE RIGHT HANDHOLD TO POSITION HIS BODY WHEN REACHING FOR COMPARTMENT
RESTOW CHECK-LIST	REMOVES CHECKLIST FROM BULKHEAD RECEPTACLE AND STOWS IN COMPARTMENT	13	SUBJECT IS STANDING FIRMLY ON VELCRO FOOT RESTRAINTS. HE USES RIGHT HAND-HOLD TO AID IN MAINTAINING HIS POSI-TION WHEN BENDING HIS BODY TO REACH COMPARTMENT

Following this maneuver the subject disposed of the cloth. He used the handholds to position his body during this maneuver, Figure 30g. The subject regained his firm stance on the velcro and from this position, with the handholds as aids, he removed and stowed the checklist, Figure 30h. At this point the task ended.

As noted previously, the hygiene subtask did not require elaborate restraint or locomotion aid setups. The combination of the velcro foot restraints and the handholds were added to this subtask to establish which restraint or locomotion aid the subject preferred. Foot restraints are not an adequate system for the hygiene maneuver because they must be removed to complete the washing of the feet. It was seen in the subtask final run that they did not add appreciably to subtask efficiency. The handhold, however, did prove to be a valuable aid to subtask performance. The subject preferred to maintain a hold on these restraint devices whenever he was performing the maneuver.

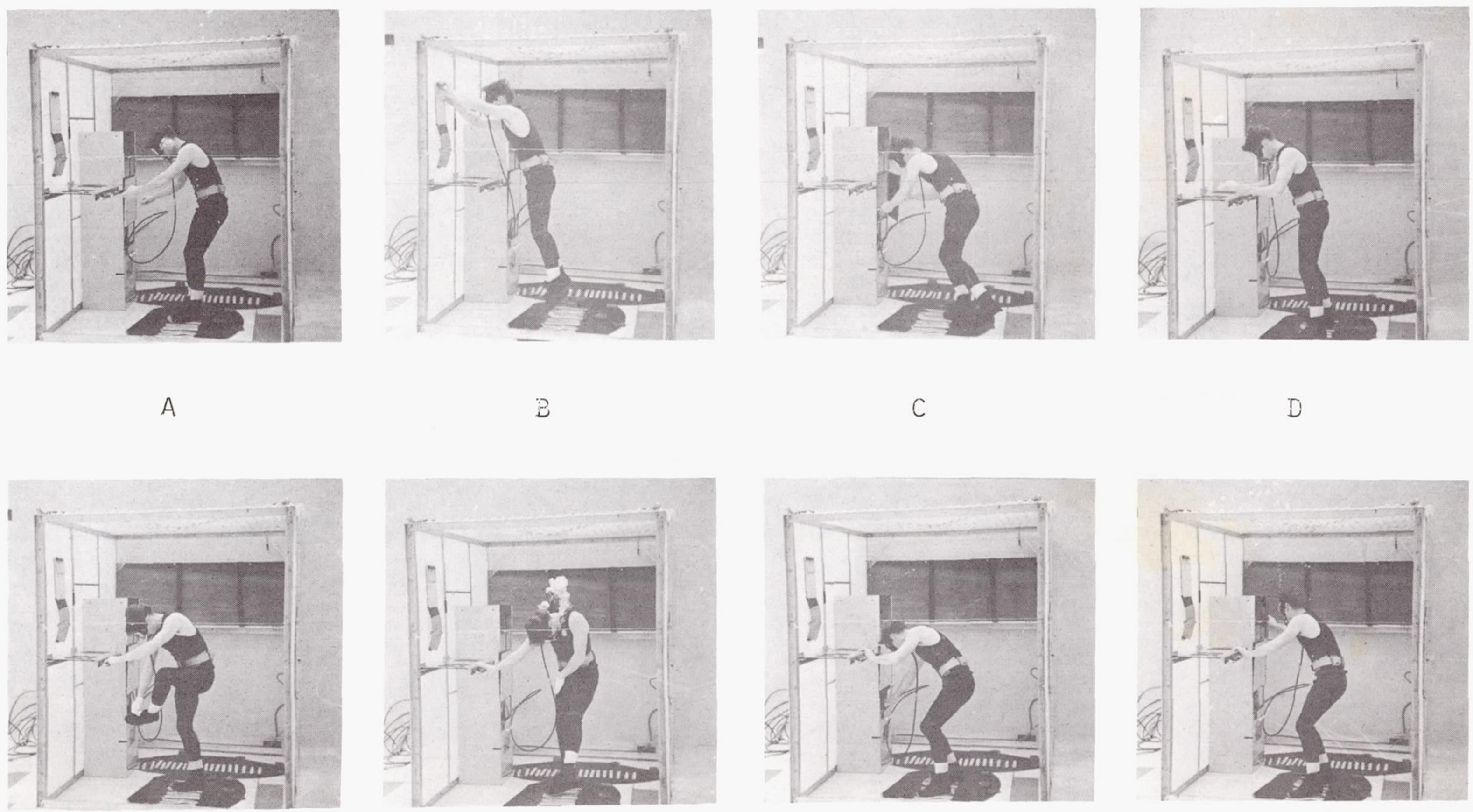
The compartment size was much larger than necessary for this subtask and it appears that a smaller compartment would increase subtask efficiency. Finally, the addition of a continuous handrail around the smaller compartment's perimeter would greatly increase task efficiency and provide increased ease of performance.

Geometry, size, and space limitation of General and Housekeeping task.--Spacecraft size requirements will necessarily impose limitations on compartment living space and work areas during extended space missions. In some situations task performance will be directly affected by these parameters. Measurements of the maximum required volume for each subtask were taken in order to determine practical compartment size and space limitations for the General and Housekeeping subtasks. The results of these measurements follow a description of compartment geometry, size, and space limitations. Figure 31 shows a plan view of the mock-up configuration for all General and Housekeeping subtasks detailing the overall dimensions.

The following compartment design was common to all subtasks. The hatch configuration was 32 inches in diameter and was mounted in the center of the 84" x 84" wall. A checklist receptacle and a convex mirror were mounted on the opposite wall above the folding work table.

A measurement of the maximum required space during the General and Housekeeping subtasks was made by analyzing the 16 mm B/W movie film taken during each final subtask run. The measurements made from the film were of the movement in the plane normal to the camera axis (the x-y plane, compartment height and width).

Movement in the transverse plane was determined by visual estimate and parallax corrections were made analytically. The x and y axis measurements and the z axis estimate were combined to determine the



A B C D

E F G H

FIGURE 30 - SEQUENCE OF HYGIENE SUBTASK

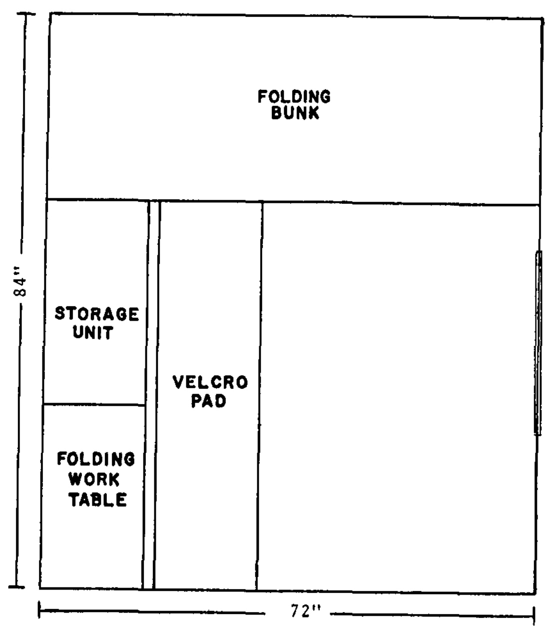


FIGURE 31 - PLAN VIEW OF GENERAL & HOUSEKEEPING MOCKUP

required working volume for each subtask. Table XVI presents the results of these measurements.

TABLE XVI

SPACE AND VOLUME ALLOCATION REQUIRED TO PERFORM GENERAL AND HOUSEKEEPING SUBTASKS

SUBTASK	ENVELOP (FT)			MAXIMUM VOLUME (CU FT)	RELATIVE COMPARTMENT VOLUME
	X	Y	Z		
FOOD HANDLING	5.9	4.6	4.7	127.6	43
EXERCISE	5.9	6.0	5.9	208.9	71
HYGIENE	5.9	4.5	3.3	87.6	30
REST-SLEEP	5.6	6.0*	3.7	124.3	42
DON-DOFF 84"x84"x72"	5.9	6.0	5.8	205.3	70
DON-DOFF 84"x84"x26"	6.0	2.1	3.0	37.8	26
DON-DOFF 84"x84"x22"	6.0	1.8	3.0	32.4	37
DON-DOFF 84"x84"x18"	6.0	1.5	3.0	27.0	37

* Subject could have used more room

The General and Housekeeping subtasks could all be performed in the 84" x 84" x 72" compartment. The volume required to perform the particular subtasks varied from 26 to 71 percent of the total compartment volume. This does not give, however, the complete picture of the subtask spatial requirements. The relative placement of the primary mock-up hardware, the work table, and the CSU required the use of a greater compartment volume than would have been necessary if the equipment were removed or more effectively placed.

An example of inefficient hardware placement was the compartment stowage unit (CSU). This unit could have been constructed beneath the work table and made an integral part of this work area. The positioning of the CSU in the food handling, don-doff, and hygiene subtasks dictated increased volume requirements. By subtracting the fixed volume of the internal equipment, a more accurate estimate is presented of the volume required to perform each General and Housekeeping subtask. In the food handling subtask the subject maintained a stationary position in front of the work table throughout

the subtask. The volume required for this subtask could have been reduced if the subject had not been required to reach to his right to stow and unstow equipment from the CSU. If the CSU had been constructed beneath the work table (this space was wasted volume in the actual subtask), a conservative estimate of the volume needed to perform the same subtask would be 60 cu ft. The major dimensional change was a reduction of the depth allowance (z) dimension.

In the don-doff subtask the positioning of the CSU was a major factor in compartment volume requirements. When the don-doff maneuver was performed in the reduced compartment volumes, it was observed that the stowage and unstowage of equipment would be the primary consideration in compartment size. In the three reduced volume don-doff runs no equipment stowage or unstowage was performed. The equipment was simply placed on the floor of the compartment. The subject could perform the subtask in all three compartment sizes. The minimum size of the three compartments was 84" x 84" x 18" or 73.5 cu ft. When the CSU was removed from the subtask and the stowage and unstowage of equipment eliminated, the space required to perform the don-doff maneuvers was reduced to its minimum practical volume. A conservative estimate for the space allocation of optimum performance is approximately 80 cu ft, 84" x 84" x 25".

The major parameter affecting the rest-sleep maneuver was the subject's size and resting requirements. The evaluation indicates that a sleeping area larger than used in this subtask is desirable. The compartment area itself was sufficient for the subject to mount the bunk and perform rest-sleep preparations, but the 72" x 27" bunk did not appear quite adequate for the 5 ft 11 in. subject, when he was in the reclined positions. The bunk length in this case was restricted by the compartment size. A larger bunk could be incorporated into the rest compartment without requiring an increased compartment volume.

The exercise subtask required the largest compartment area. In this case, the total compartment volume of 208.9 cu ft represented the minimum volume needed to perform this subtask. A general rule for minimum compartment volume for exercise maneuvers would be to use the measured length of the subject with his arms outstretched above his head to determine the minimum compartment dimension. At least two of the compartment dimensions would be dictated by this measurement. The third dimension is dictated by the measured width of the subject with his arms outstretched horizontally at shoulder height.

The spatial requirements for the hygiene subtask were quite similar to those of the food handling subtask. In both cases the subject primarily remained in one fixed standing position on the velcro foot restraints. The only required deviation from this position was for the stowage and unstowage of equipment from the CSU. During these periods the subject was required to alter his position to provide a better access to the CSU.

Restraints and locomotion aids proved to be the main factor in dictating compartment size and space allocations. The use of restraints and locomotion aids such as the velcro foot pads in most cases reduced the subject's dependence on the compartment walls and protuberances for points of stability. As the tests indicated, many subtasks require only small compartment volumes for efficient task performance. An optimum compartment volume is attained where the advantages of compartment walls and protuberances as points of stability are ideal even though other restraints and locomotion aids are provided simply because these points of stability are readily available and are quasi-randomly distributed over the total work area. For the food handling subtask the foot restraint provided the most efficient subtask performance in the large compartment volume. In the don-doff subtask the foot restraints were not as efficient. However, when the compartment volume was reduced, the task performance efficiency increased steadily, when the subject could utilize the walls of the compartment for support. Combining all the subtasks of the General and Housekeeping task would require a compartment volume of approximately 208 cu ft with a configuration of 84" x 84" x 72". The exercise subtask, which required the largest compartment volume, would dictate this size and configuration.

As noted in the study phase of the contract, the desiderata is to make the living quarters distinct from work quarters. In terms of the General and Housekeeping task, all subtasks would be categorized as living quarters functions. From these studies a suggested volume for the living quarters for earth-orbiting space stations of 600 cu ft was envisioned for extended periods (over 6 months). The minimum tolerable volume suggested for extended periods was 200 cu ft. The present research effort on the General and Housekeeping task functions indicates that this upper estimate tends to be high. It appears that the 200 cu ft compartment volume is closer to the optimum space requirement for a single compartment configuration since it offers optimal restraint and locomotion characteristics. It is, however, noted here that this space allocation is only optimal for the subtasks studied during the General and Housekeeping task. Other living requirement maneuvers required on long term space missions may require additional volume allocations and variations in compartment configuration.

Conclusions.--The General and Housekeeping task demonstrated that the normal requirements of work, exercise, eating, rest, and hygiene that will be an integral part of any long term space mission can be performed in a zero gravity environment, with the aid of certain restraint and locomotion systems. In most cases the restraint and locomotion aid systems are basic, such as the handholds or positive foot restraint configurations. However, in some tasks more sophisticated systems are required. The results of the zero gravity simulation of the General and Housekeeping task have shown that these restraint and locomotion aid systems can be defined and evaluated. Table XVII summarizes the optimum restraints and locomotion aids for the General and Housekeeping subtasks. It is also evident from

the simulations that certain systems, such as the handholds, handrails, or the velcro foot restraints, can be used as both restraints

TABLE XVII

OPTIMUM RESTRAINT AND LOCOMOTION AIDS FOR THE GENERAL AND HOUSEKEEPING TASK MANEUVERS

SUBTASKS	RESTRAINTS	LOCOMOTION AIDS
DON-DOFF	HANDHOLDS HANDRAILS VELCRO SANDALS	HANDHOLDS HANDRAILS VELCRO SANDALS
REST-SLEEP	SEAT BELT RESTRAINTS VELCRO SANDALS	VELCRO SANDALS
FOOD HANDLING	HANDHOLDS HANDRAILS VELCRO SANDALS	HANDHOLDS HANDRAILS VELCRO SANDALS
EXERCISE	HANDHOLDS HANDRAILS VELCRO SANDALS TWO WAIST TETHERS	HANDHOLDS HANDRAILS
HYGIENE	HANDHOLDS HANDRAILS	HANDHOLDS HANDRAILS VELCRO SANDALS

and locomotion aids. The handholds or perimeter handrails, in particular, have proved to be an excellent general purpose combination restraint and locomotion aid. Individual handholds are small and can be placed in many positions without affecting compartment size or spacing. The perimeter handrail provides an infinite number of handhold positions, and, again, does not affect the compartment configuration.

Results of the General and Housekeeping task simulations have shown that in many cases task maneuver efficiency was increased as the compartment volume was decreased. It also appeared that each of the subtasks, don-doff, food handling, rest-sleep, exercise, and hygiene, required a different compartment volume. These volume variations can be precisely determined using the simulated zero gravity environment provided by water immersion. Present research estimates seem adequate in terms of volume allocations. Whereas, 600 cu ft per man is suggested as a minimum volume for long term missions, the results of the General and Housekeeping subtasks indicate that 200 cu ft per man is sufficient for living quarters. Our analysis indicates that living quarters surface area requirements compare

more favorably to the predicted estimate from previous research. The mock-ups used in the General and Housekeeping task presented a functional surface area of approximately 41 sq ft. Comparing this result with previous predictions for living quarters, suggests a minimum floor area of 45 sq ft for living quarters allocation.

Equipment Operation

Equipment Operation consists of the performance of representative tasks essential to the maintenance and operation of a spacecraft in flight. The tasks involved are divided into three categories: (1) work station operation, (2) console operation, and (3) maintenance and repair. The test subject was called upon to adjust and set gauges and dials, take instrument readings, and perform simple calculations. The console operation involved the manual configuration of a guidance and navigation display console. Each step was performed according to a predetermined checklist mounted on the console. The maintenance and repair portion of the task entailed the performance of basic support functions essential to the operational status of inflight hardware. The subject removed and replaced tubes, performed wiring tasks, as well as disassembling and assembling a valve component representative of existing precision space hardware, Figure 32.

The mock-up configuration for the Equipment Operation task is the basic IVA compartment, measuring 84" x 84" x 72". A G+N control panel was placed inside the compartment with the complement of small hand tools and replacement parts to be used in the simulation. Figure 33 shows the Equipment Operation mock-up in the water immersion simulation mode.

A series of preliminary tests was conducted to determine the restraints and locomotion aids most applicable to the task. This series was conducted in the manner similar to the preliminary evaluation for the General and Housekeeping task. The results of this evaluation are summarized in an evaluation matrix. An explanation of the rating system was presented in the General and Housekeeping preliminary evaluation section.

Preliminary restraint and locomotion aid evaluation.--The Equipment Operation task for the preliminary evaluation was a shortened version of the final task run. This reduced length task version included all the important maneuvers of the complete final task run. The restraint modes evaluated in the Equipment Operation task were the following: chair and seat belt, positive foot restraint, toe traps, handholds, waist tether (2), waist tether (1), velcro sandals, and perimeter handrails. The locomotion aids evaluated in the Equipment Operation task were the following: perimeter handrail, soaring-handhold combination, velcro sandals, and handholds. The restraints were evaluated at three basic positions or stations.

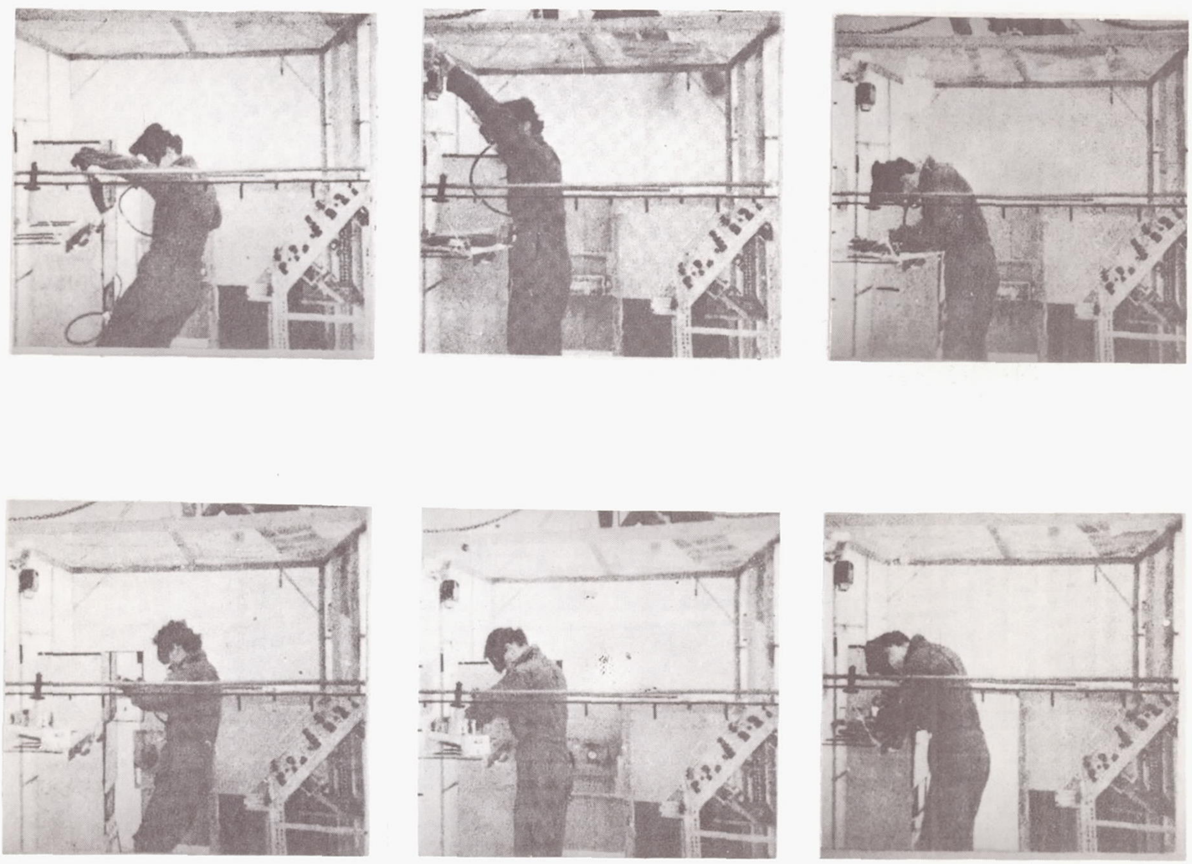


FIGURE 32 - REPRESENTATIVE SPACE HARDWARE

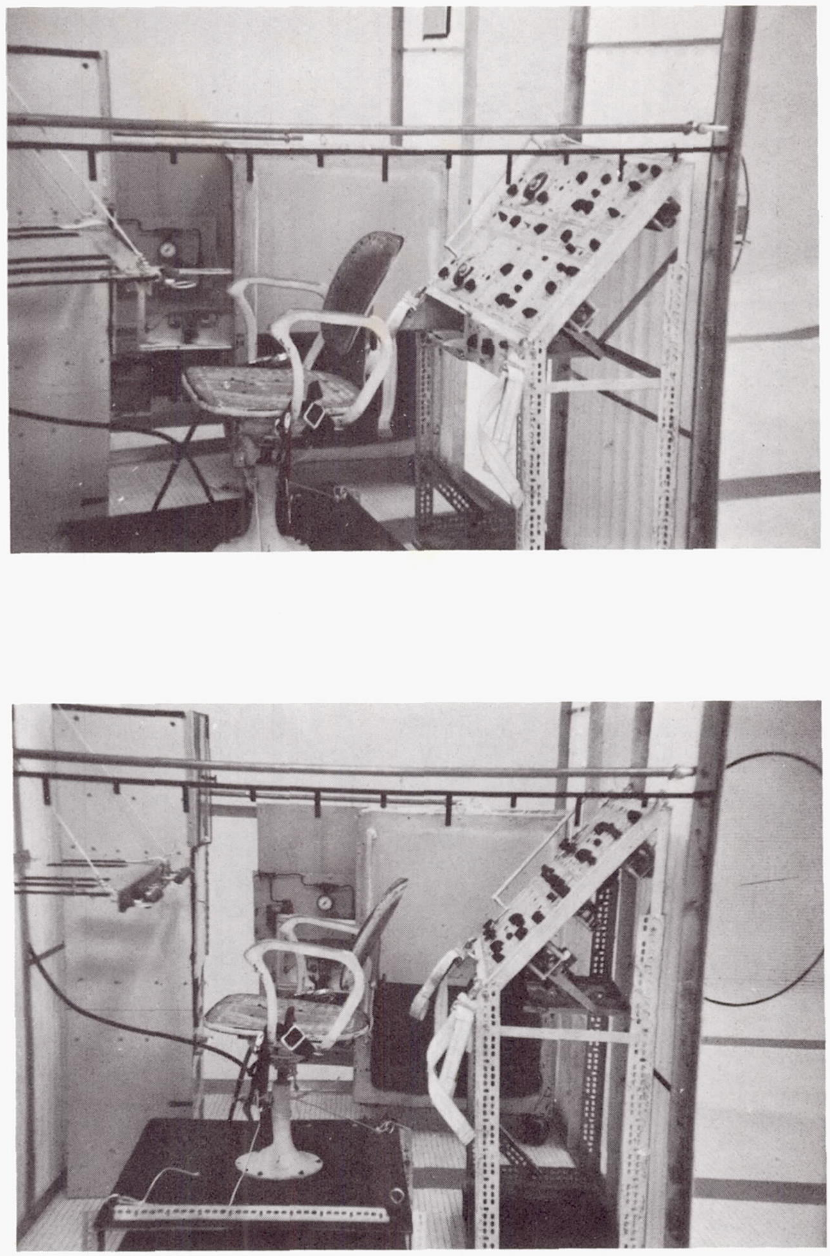


FIGURE 33 - MOCKUP CONFIGURATION FOR THE EQUIPMENT OPERATION SIMULATION

The locomotion aids were evaluated for movement between these three stations. Table XVIII summarizes the variations of positions, restraints, and locomotion aids evaluated through the seven preliminary evaluation runs. The effects of weightless simulation on the data gathering and calculation tasks performed at the work table and at the EMC were determined during the preliminary evaluation run.

A similar test was also performed on the surface to act as a control. The subject was required to perform routine calculations on a clipboard writing pad while seated at the work desk comparable with the simulation work table and chair configuration in the water immersion runs. In a second surface run the subject performed the calculation task using a clipboard writing pad while standing at the desk. This task was comparable to the writing performance at the work table while using such restraints as the foot restraints or waist tether, etc., in the water simulation runs. A third surface test was performed using the same clipboard configuration while standing free of any table or chair device. The subject held the board in his left hand while writing. This task is compared with the performance at the EMC in the underwater simulation. A final surface task run was performed at the conclusion of the underwater simulation tasks to determine learning factors involved in the task repetition. Comparison of the surface and water immersion runs indicated that simple mathematical calculations were not the type task to evaluate the effect of various configuration and restraint effects on performing simple writing tasks.

The results of the preliminary evaluation runs were compared on a time basis for the eight specific task elements comprising the Equipment Operation task and are given in Table XIX. The comparative times were considered along with the evaluation technique previously described to derive the evaluation matrix of Table XX. From this evaluation it was determined that the most effective restraint aids were (1) handholds--due to the close proximity of equipment in the mock-up the subject had an available supply of handholds, and (2) toe traps--during tasks at the work table, when the subject needed both hands to hold and handle equipment, toe traps were found to be most suited for holding him in position. The most effective locomotion aid proved to be handholds, due to the small distance to be traversed and the proximity of available handholds.

The final test-data run was an expanded version of the preliminary evaluation runs employing the restraints and locomotion aids chosen during the preliminary run. The following is a detailed description of the final test run. Table XXI details the performance analysis for the simulation investigation of Equipment Operation tasks.

TABLE XVIII

EQUIPMENT OPERATION - LOCOMOTION AIDS AND RESTRAINTS

RUN	POSITIONS	RESTRAINTS	MOTION AIDS
A	CONSOLE WORK TABLE EQUIPMENT MODULE CABINET	CHAIR-SEAT BELT CHAIR-SEAT BELT POSITIVE FOOT RESTRAINTS	HANDHOLDS
B	CONSOLE WORK TABLE EQUIPMENT MODULE CABINET	TOE TRAPS VELCRO FOOT RESTRAINTS VELCRO FOOT RESTRAINTS	VELCRO
C	CONSOLE WORK TABLE EQUIPMENT MODULE CABINET	VELCRO FOOT RESTRAINTS TOE TRAPS HANDHOLDS-HANDRAILS	VELCRO
D	CONSOLE WORK TABLE EQUIPMENT MODULE CABINET	HANDHOLD-HANDRAILS HANDHOLD-HANDRAILS HANDHOLD-HANDRAILS	HANDRAILS
E	CONSOLE WORK TABLE EQUIPMENT MODULE CABINET	NO RESTRAINTS NO RESTRAINTS NO RESTRAINTS	HANDHOLDS SOARING
F	CONSOLE WORK TABLE EQUIPMENT MODULE CABINET	ONE WAIST TETHER ONE WAIST TETHER ONE WAIST TETHER	HANDHOLDS SOARING
G	CONSOLE WORK TABLE EQUIPMENT MODULE CABINET	TWO WAIST TETHERS TWO WAIST TETHERS TWO WAIST TETHERS	HANDHOLDS SOARING

Task analysis.--The subject entered the compartment through the hatch using handholds as his locomotion aid. He positioned himself in front the the G+N console. His first task was to adjust

TABLE XIX

EQUIPMENT OPERATION

TIME COMPARISONS OF THE PRELIMINARY EVALUATION RUNS

SUBTASK ELEMENT	RUN TIME - SEC.						
	A	B	C	D	E	F	G
TOP DISPLAY	25	21	40	33	35	44	35
MIDDLE DISPLAY	14	12	10	15	10	12	09
BOTTOM DISPLAY	28	30	30	24	27	22	28
FIRST CAL. (GAUGE)	132	105	55	78	74	85	65
FLUID LINE	60	30	20	23	21	17	10
WIRES	62	20	30	43	28	33	33
SECOND CAL. (TABLE)	75	75	62	72	72	87	73
TUBES	33	20	43	33	27	23	18
TOTAL TASK TIME (INCLUDES MISC. TASKS)	1095	840	575	760	660	773	600

the dials to a prescribed setting, referring to a checklist mounted on the console. He maintained a stable attitude throughout this entire operation by means of specifically located handholds, using the control knobs on the panel and the checklist board mounted on the lower left hand side of the console, Figure 34a. Having completed the panel set up, he turned to the CSU and unstowed the camera. The subject then floated upward and steadied himself with his left foot against the console. Evaluation of the preliminary test run indicated that it was necessary to move away from the panel in this way to photograph it completely, Figure 34b.

The subject returned to the CSU by pushing off from the handrail on the front wall. He restowed the camera and unstowed the checklist clipboard and several hand tools using the handholds on the CSU and the adjacent table for support.

Positioning himself at the EMC the subject opened the cabinet door and withdrew the fluid panel on its slide track, Figure 34c. He used the handhold on the side of the EMC as his restraint. He

TABLE XX EVALUATION MATRIX FOR EQUIPMENT OPERATION TASKS

	RESTRAINTS								MOTION AIDS			
	VELCRO FOOT RESTRAINTS	HANDHOLDS	TETHERS (2)	TETHERS (1)	CHAIR	POSITIVE FOOT RESTRAINTS	TOE TRAPS	NO RESTRAINTS	HANDRAILS	HANDHOLDS	SOARING	VELCRO FOOT RESTRAINTS
TO G+N DISPLAY	N	N	N	N	N	N	N	N	3	3	2	2
PERFORM SETUP	3	4	3	2	3	3	3	1	N	N	N	N
PHOTOGRAPH	1	4	2	2	1	2	2	3	N	N	N	N
TO CSU	N	N	N	N	N	N	N	N	N	3	2	2
UNSTOW CLIPBOARD	2	4	1	1	1	1	1	2	N	N	N	N
TO EMC	N	N	N	N	N	N	N	N	1	3	2	2
UNSTOW PANEL	2	4	1	1	0	2	2	1	N	N	N	N
CALCULATION TASK	2	4	1	1	0	2	2	1	N	N	N	N
TO CSU	N	N	N	N	N	N	N	N	1	3	2	2
UNSTOW TOOLS	2	4	1	1	1	1	1	2	N	N	N	N
TO EMC	N	N	N	N	N	N	N	N	1	3	2	2
FLUID LINE TASK	2	4	1	1	0	2	2	2	N	N	N	N
ELECTRICAL UNIT	2	4	1	1	0	2	2	1	N	N	N	N
TO WORK TABLE	N	N	N	N	N	N	N	N	1	3	2	2
INSTALL CAMERA	2	4	2	2	0	2	3	1	N	N	N	N
UNSTOW TOOLS	2	4	2	2	1	2	3	1	N	N	N	N
CONNECTION TASKS	2	4	2	2	1	2	3	1	N	N	N	N
RESTOW TOOLS	2	4	2	2	1	2	3	1	N	N	N	N
CALCULATION TASK	3	3	0	0	1	2	3	0	N	N	N	N
STOW CHECK LIST	2	4	2	2	1	2	3	1	N	N	N	N
UNSTOW MODULE	2	4	2	2	2	0	2	3	N	N	N	N
TUBE REPLACEMENT	2	4	2	2	1	2	3	1	N	N	N	N
UNIT TO EMC	N	N	N	N	N	N	N	N	1	3	2	2
INSTALL UNIT	2	4	1	1	0	2	2	1	N	N	N	N
CLOSE CABINET	2	4	1	1	0	2	2	1	N	N	N	N
RATING (0-100)	51	99	38	38	17	49	60	31	33	75	50	50

N - NOT APPLICABLE

TABLE XXI.--PERFORMANCE ANALYSIS OF EQUIPMENT OPERATION †

SUBTASK ELEMENT	DESCRIPTION	TIME SEC.	COMMENTS
ENTER HATCH.	TRANSFERS THROUGH HATCH AND MOVES TO G+N DISPLAY. POSITIONS BODY STANDING IN FRONT OF DISPLAY.	20	SUBJECT USES HANDHOLDS WHILE MOVING THROUGH HATCH AND WHILE POSITIONING BODY AT DISPLAY PANEL.
PERFORM TOP DISPLAY OP-ERATIONS.	UNSTOWS CHECKLIST. READS DISPLAY INSTRUCTIONS AND SETS UP CONTROLS ON G+N TOP DISPLAY.	34	SUBJECT USES THE CHECKLIST TRAY AS HIS HANDHOLD THROUGHOUT THIS MANEU-VER. HE SOMETIMES RELEASES THIS HANDHOLD AND USES THE CONTROL KNOBS HE IS SETTING AS HANDHOLDS. HE PLACES HIS FEET AGAINST THE BOTTOM OF THE G+N DISPLAY AND MAINTAINS THIS POSITION THROUGHOUT THE SETUP MANEU-VER.
PERFORM MID-DLE DISPLAY OPERATIONS.	READS DISPLAY INSTRUC-TIONS AND SETS UP CONTROLS ON G+N MIDDLE DISPLAY.	13	
PERFORM BOT-TOM DISPLAY OPERATIONS.	READS DISPLAY INSTRUC-TIONS AND SETS UP CONTROLS ON G+N BOTTOM DISPLAY.	20	
PHOTOGRAPH G+N DISPLAY.	MOVES TO COMPARTMENT STO-WAGE UNIT (CSU). UNSTOWS CAMERA, POSITIONS IN FRONT OF DISPLAY AND PHOTOGRAPHS DISPLAY. RESTOWS CAMERA IN CSU. RESTOWS CHECK-LIST BOARD.	24	SUBJECT DOES NOT CHANGE HIS FOOT POSITION UNTIL HE HAS REMOVED THE CAMERA FROM THE CSU. HE THEN PUSHES OFF THE FLOOR WITH HIS FEET AND DRIFTS AGAINST THE WORK TABLE BEFORE PHOTOGRAPHING THE DISPLAY.

† ref. fig. 34

TABLE XXI.--PERFORMANCE ANALYSIS OF EQUIPMENT OPERATION - CONTINUED

SUBTASK ELEMENT	DESCRIPTION	TIME SEC.	COMMENTS
UNSTOW CHECK-LIST CLIPBOARD AND TOOLS.	OPENS CSU. REMOVES CLIP-BOARD AND TOOLS. INSERTS TOOLS IN FLIGHT SUIT POC-KET. CLOSES CSU.	10	SUBJECT USES HANDHOLDS ON TABLE AND ON CSU TO POSITION FOR THIS MANEUVER.
UNSTOW FLUID PANEL.	MOVES TO EQUIPMENT MODULE CABINET (EMC). OPENS EMC AND UNSTOWS FLUID PANEL ON SLIDE TRACK.	10	SUBJECT USES VERTICAL HANDHOLD ON EMC FOR POSITIONING AND AS AN AID WHEN OPENING THE EMC.
PERFORM FIRST VALVE READING AND CALCULA-TION MANEUVER.	OPENS FLUID VALVE AND OB-SERVES GAUGE READING WITH VALVE IN THE FULL OPEN POSITION. UNSTOWS PENCIL FROM FLIGHT SUIT. RECORDS GAUGE READING ON CLIPBOARD AND PERFORMS MATHEMATICAL CALCULATIONS. SIGNS CLIP-BOARD BELOW CALCULATIONS. CLOSES VALVE AND RESTOWS PENCIL IN FLIGHT SUIT.	45	SUBJECT USES SLIDE TRACK AND CABINET STRUCTURE AS HANDHOLDS WHEN PERFORM-ING THIS MANEUVER. HE PERFORMS THE WRITING MANEUVER BY PLACING THE CLIP-BOARD ON TOP OF THE EMC AND USING THE EMC STRUCTURE TO MAINTAIN HIS POSITION.
PERFORM FIRST FLUID LINE OPERATION.	ATTACHES CLIPBOARD TO TOP OF EMC. UNSTOWS TOOLS FROM FLIGHT SUIT. DIS-CONNECTS AND RECONNECTS FLUID LINES. RESTOWS TOOLS IN FLIGHT SUIT.	12	
TRANSFER FLUID PANEL TO WORK TABLE.	DETACHES FLUID UNIT FROM EMC. MOVES TO WORK TABLE WITH CLIPBOARD AND FLUID UNIT. SECURES UNIT TO	14	SUBJECT TRANSFERS BOTH CLIPBOARD AND FLUID UNIT TO WORK TABLE IN SAME MOVEMENT, USING EMC AND CSU STRUC-TURES AS LOCOMOTION AIDS.

TABLE XXI.--PERFORMANCE ANALYSIS OF EQUIPMENT OPERATION - CONTINUED

SUBTASK ELEMENT	DESCRIPTION	TIME SEC.	COMMENTS
	LEFT SIDE OF WORK TABLE. VELCROES CLIPBOARD TO RIGHT SIDE OF WORK TABLE.		
INSTALL TASK RECORDER CAMERA AND LIGHTING.	OPENS CSU AND REMOVES PORTABLE CAMERA AND LIGHT. ATTACHES CAMERA TO RECEPTACLE ABOVE WORK TABLE (LEFT SIDE). ATTACHES LIGHT TO RECEPTACLE ABOVE WORK TABLE (RIGHT SIDE).	15	SUBJECT PLACES HIS FEET IN TOE TRAPS AND USES THIS RESTRAINT TO POSITION HIS BODY. HE MAINTAINS HIS FOOTHOLD IN THE RESTRAINT EVEN WHEN REACHING TO INSTALL THE CAMERA AND LIGHT.
PERFORM SECOND VALVE READING AND CALCULATION MANEUVER.	OPENS FLUID VALVE AND OBSERVES GAUGE READING WITH VALVE IN FULL OPEN POSITION. UNSTOWS PENCIL FROM FLIGHT SUIT. RECORDS GAUGE READING ON CLIPBOARD AND PERFORMS MATHEMATICAL CALCULATIONS. SIGNS CLIPBOARD BELOW CALCULATIONS. CLOSES VALVE AND RESTOWS PENCIL IN FLIGHT SUIT.	38	TOE TRAPS HOLD SUBJECT FIRM WHILE PERFORMING TORQUE OPERATION ON FLUID LINES.
PERFORM SECOND FLUID LINE OPERATION.	UNSTOWS TOOL FROM FLIGHT SUIT. DISCONNECTS AND RECONNECTS FLUID LINES. RESTOWS TOOL IN FLIGHT SUIT.	14	
TRANSFER FLUID PANEL TO EMC.	DETACHES FLUID PANEL FROM WORK TABLE. MOVES TO EMC AND REATTACHES UNIT ON	10	SUBJECT SOARS INTO POSITION AT EMC AFTER REMOVING HIS FEET FROM THE TOE TRAPS.

TABLE XXI.--PERFORMANCE ANALYSIS OF EQUIPMENT OPERATION - CONTINUED

SUBTASK ELEMENT	DESCRIPTION	TIME SEC.	COMMENTS
	SLIDE TRACK. RESTOWS FLUID UNIT IN EMC.		
UNSTOW ELECTRICAL PANEL.	PULLS ELECTRICAL PANEL OUT OF EMC ON SLIDE TRACK.	2	
PERFORM FIRST ELECTRICAL UNIT OPERATION	REMOVES TOOLS FROM FLIGHT SUIT. REMOVES 5 WIRES FROM PANEL A AND REPLACES 5 WIRES ON PANEL B. RESTOWS TOOLS IN FLIGHT SUIT.	30	SUBJECT ENCOUNTERS NO DIFFICULTY IN MANIPULATING WIRES OR TOOLS DURING THIS MANEUVER.
TRANSFER ELECTRICAL PANEL TO WORK TABLE.	DETACHES ELECTRICAL PANEL FROM EMC. MOVES TO WORK TABLE AND SECURES ELECTRICAL PANEL TO LEFT SIDE OF WORK TABLE.	17	SUBJECT USES EMC AND CSU STRUCTURES AS LOCOMOTION AIDS.
PERFORM SECOND ELECTRICAL UNIT OPERATION	REMOVES TOOLS FROM FLIGHT SUIT. REMOVES 5 WIRES FROM PANEL A AND REPLACES 5 WIRES ON PANEL B. RESTOWS TOOLS IN FLIGHT SUIT.	35	
TRANSFER ELECTRICAL PANEL TO EMC.	DETACHES ELECTRICAL PANEL FROM WORK TABLE. MOVES TO EMC AND REATTACHES UNIT ON SLIDE TRACK. RESTOWS ELECTRICAL PANEL IN EMC.	26	SUBJECT SOARS TO EMC WITH ELECTRICAL PANEL IN RIGHT HAND. HE USES THE CSU AS POINTS OF STABILITY AS HE PERFORMS THIS MANEUVER.

TABLE XXI.--PERFORMANCE ANALYSIS OF EQUIPMENT OPERATION - CONTINUED

SUBTASK ELEMENT	DESCRIPTION	TIME SEC.	COMMENTS
UNSTOW ELECTRONIC MODULE PANEL.	PULLS ELECTRONIC MODULE PANEL OUT OF EMC ON SLIDE TRACK.	5	
PERFORM FIRST ELECTRONIC MODULE OPERATION.	REVERSES TUBES A AND B ON ELECTRONIC MODULE. REVERSES TUBES C AND D ON MODULE.	25	SUBJECT AGAIN USES STRUCTURE OF EMC TO STEADY HIS POSITION.
TRANSFER ELECTRONIC MODULE TO WORK TABLE.	DETACHES ELECTRONIC MODULE FROM EMC. MOVES TO WORK TABLE AND SECURES MODULE TO LEFT SIDE OF WORK TABLE.	19	SUBJECT USES HANDHOLDS ON WORK TABLE FOR THE FIRST TIME AS LOCOMOTION AIDS WHEN MOVING TO WORK TABLE.
UNSTOW TUBE CANISTER.	OPENS CSU. REMOVES AND VELCROES CANISTER TO RIGHT SIDE OF WORK TABLE.	6	SUBJECT INSERTS FEET IN TOE TRAPS AND MAINTAINS THIS POSITION.
PERFORM SECOND ELECTRONIC MODULE OPERATION.	REMOVES DEFECTIVE TUBES FROM MODULE (TUBES A, B, C, AND D) AND DISCARDS IN WASTE COMPARTMENT. REMOVES NEW TUBES FROM TUBE CANISTER AND REPLACES IN RECEPTACLES A, B, C, AND D.	90	SUBJECT NOTES THAT TUBES CAN BE REMOVED AND REPLACED IN CANISTER WITH ONE HAND. REMOVING TUBES FROM MODULE HOWEVER, IS A TWO-HANDED OPERATION.
RESTOW TUBE CANISTER.	OPENS CSU. REMOVES TUBE CANISTER FROM WORK TABLE AND STOWS IN CSU. CLOSES CSU.	20	SUBJECT REMAINS IN TOE TRAPS UNTIL THIS MANEUVER IS COMPLETE.

TABLE XXI.--PERFORMANCE ANALYSIS OF EQUIPMENT OPERATION - CONTINUED

SUBTASK ELEMENT	DESCRIPTION	TIME SEC.	COMMENTS
TRANSFER ELECTRONIC MODULE TO EMC.	DETACHES ELECTRONIC MODULE FROM WORK TABLE. MOVES TO EMC AND REATTACHES UNIT ON SLIDE TRACK. RESTOWS ELECTRONIC MODULE IN EMC. CLOSES EMC DOOR AND LOCKS.	70	SUBJECT NOTES THAT HE REQUIRES A FIRM HANDHOLD WHEN TIGHTENING THE ELECTRICAL CABLE ON THE ELECTRONIC MODULE.
PRECISION VALVE MAINTENANCE PREPARATION.	MOVES TO WORK TABLE. OPENS CSU. REMOVES TOOL KIT AND VELCROES KIT TO RIGHT SIDE OF WORK TABLE. REMOVES PRECISION VALVE CANISTER AND VELCROES TO LEFT SIDE OF WORK TABLE.	50	SUBJECT PLACES FEET IN TOE TRAPS AND MAINTAINS THIS STANDING POSITION THROUGHOUT THE PRECISION VALVE MANEUVER.
PRECISION VALVE MAINTENANCE.	DISASSEMBLES AND REASSEMBLES PRECISION VALVE.	400	SUBJECT HAS NO DIFFICULTY WITH SMALL PARTS MANIPULATION.
PRECISION VALVE MAINTENANCE.	PLACES VALVE IN CANISTER AND RESTOWS IN CSU. PLACES TOOLS IN TOOL KIT AND RESTOWS IN CSU.	30	

then actuated a globe type valve located on the fluid panel. With the valve completely open he recorded the gauge reading on his clipboard. Using the top of the EMC as support he performed a prescribed calculation utilizing the reading from the gauge, Figure 34d. The subject's feet had a tendency to float about during this task.

Upon completion of the calculation the subject velcroed his clipboard to the top of the EMC and unstowed the hand tools from his flight suit. He disconnected a fluid line on the panel, inspected it, and reconnected it again, using the wrench provided. The fluid panel served as his handhold during this procedure, Figure 34e.

This same task was then repeated at the work table. The subject detached the fluid panel from the EMC and moved to the work table, carrying both the fluid panel and the clipboard with him. He pushed away from the EMC, traversing the several feet necessary to position himself in front of the work table by soaring, Figure 34f. He put the fluid panel on the left and the clipboard on the right side of the table and then secured his feet in the toe traps.

With his feet securely in the toe traps he leaned to the right and unstowed the camera and light from the CSU. Reaching above the work table he attached the camera and light to their brackets on the wall, Figure 34g. The subject then proceeded to open the valve on the fluid panel, read the gauge, and perform the calculations using the clipboard, Figure 34h. He had no trouble maintaining a stable position with the toe traps. After completing the calculation the subject unstowed the wrench from his flight suit and disconnected and connected the fluid line on the panel.

The fluid panel was then removed from the work table and transferred to the EMC. The subject reattached the panel to the slide track and returned it to its original position inside the EMC. While attaching the panel to the slide track, the subject's feet floated about freely but he maintained body position with the use of the vertical handhold on the EMC, Figure 34i. After the panel was secured he used the handhold on the side of the EMC for restraint.

The subject withdrew the electrical panel from the EMC. He performed the wiring task by removing 5 wires from one panel and replacing them on another. Due to the low body torque requirements of this task the subject had no trouble maintaining stability. The electrical panel served as a handhold restraint during the task, Figure 34j.

The electrical panel was then detached from the EMC and transported to the work table. To move, the subject pushed away from the EMC, turned, and grasped the handhold on the front of the work table. He placed the electrical panel on the left side of the table and

secured his feet in the toe traps. While securing his feet he steadied himself by grasping the work table handholds. He unstowed the tools from his flight suit and repeated the electrical wiring task, Figure 34k. The toe traps held him firmly in place during the task. The combination of upright posture and enhanced visual access aided the performance of the wiring task.

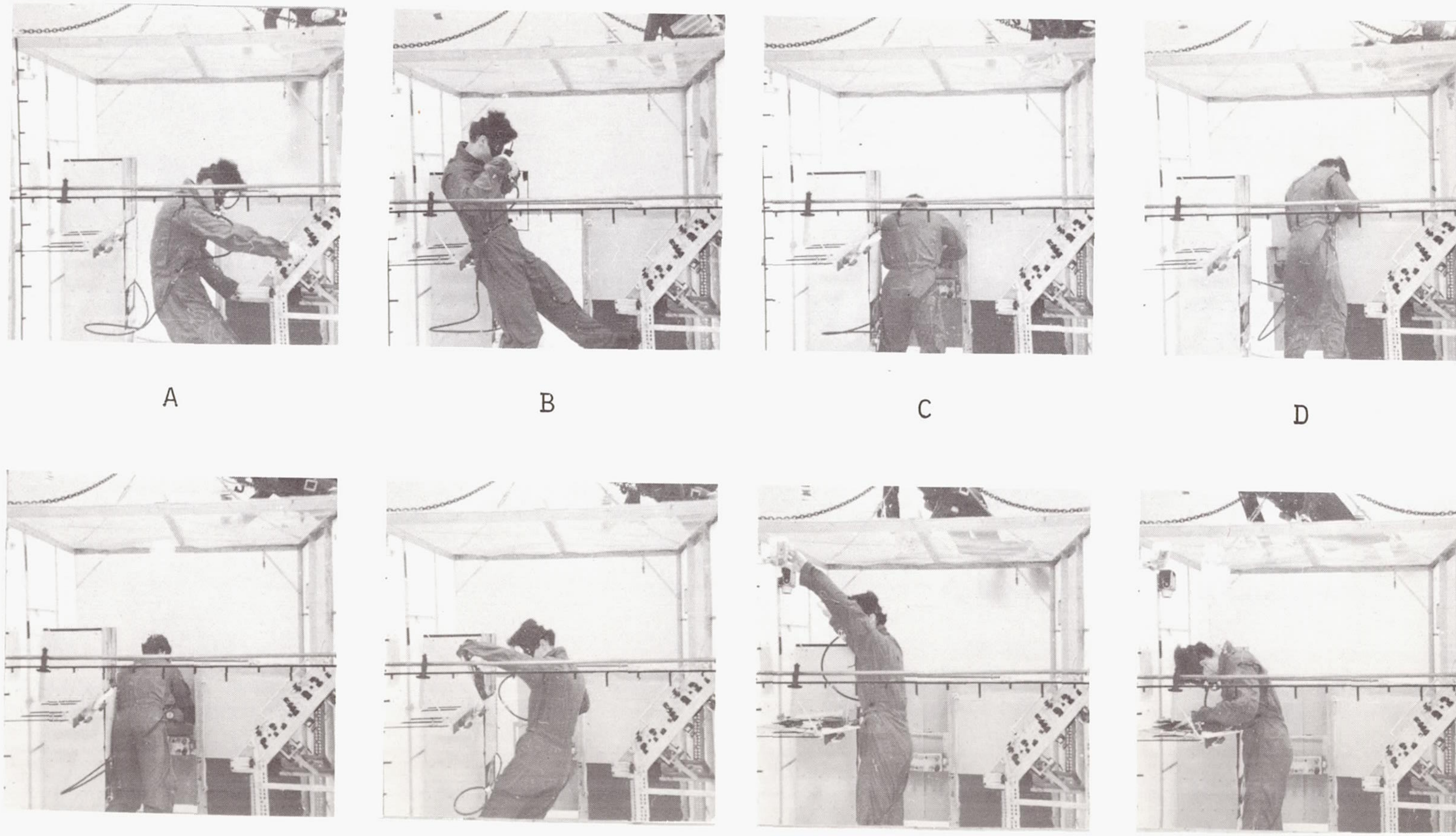
After restowing the tools in his flight suit, he picked up the electrical panel and moved to the EMC. He reattached the electrical panel on its slide track using the slide track as his only means of restraint, Figure 341. After he pushed the electrical panel back into the EMC, he withdrew the electronic module panel to perform the tube replacement task. The subject reversed tubes A and B and tubes C and D on the electronic module. He then detached the electronic module panel from the slide track and transferred it to the work table. He turned from the EMC and grasped the work table handhold as a locomotion aid. He positioned himself in front of the work table, placing the electronic module on the left side, and secured his feet in the toe traps.

With his feet in the toe traps he unstowed a tube canister from the CSU and velcroed it to the right side of the work table, Figure 34m. He then performed a second tube replacement task, discarding tubes A through C and replacing them with tubes from the canister, Figure 34n. Discarded tubes were deposited in the waste compartment of the CSU. Toe traps again proved quite adequate for the task. The tube canister was then restowed in the CSU.

The electronic module was returned to the EMC. When reattaching the electronic module to the slide track, the subject's body was in constant contact with the CSU, aiding in stabilization, Figure 34o. Both hands were required to attach the module. The panel was inserted back into the EMC and the cabinet door was closed. The subject used the EMC handhold as a restraint aid when closing the door.

He pushed away from the EMC and grasped the corner of the CSU. In this way he positioned himself in front of the CSU and, using the door handles as restraint aids, unstowed the tool kit and precision valve canister. These were placed on the work table and the subject then inserted his feet into the toe traps. He proceeded to remove the precision valve from its container and disassemble it, Figure 34p. He had no trouble maintaining stability or manipulating the small parts. At the completion of the disassembly, the valve was reassembled and returned to its containers. The valve canister and the tool kit were then restowed. This ended the Equipment Operation task sequence.

<u>Geometry, size, and space limitations of Equipment Operation task</u>.--Placement and density of equipment is the controlling human factors element in the performance of work tasks for future space



A B C D

E F G H

FIGURE 34 - EQUIPMENT OPERATION TASK SEQUENCE

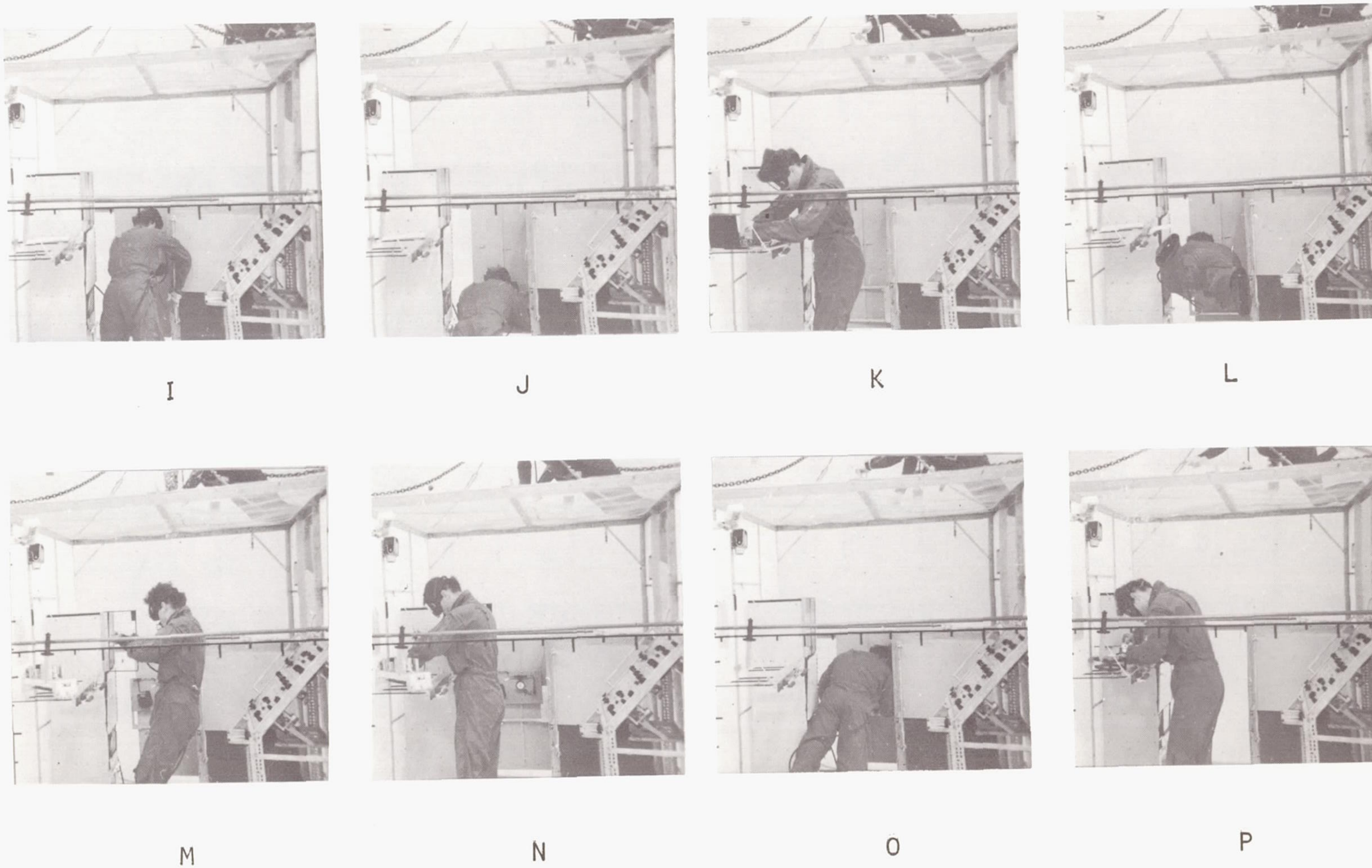


FIGURE 34 - EQUIPMENT OPERATION TASK SEQUENCE-CONTINUED

missions. Little is known, however, about actual equipment design since this depends on as yet unspecified flight hardware criteria. Thus, the approach in the simulation of the Equipment Operation task was to produce a system that emphasized the human factors interaction and characteristics of system operation. Measurement of the maximum required space envelop and compartment volume for the various task maneuvers was made to determine practical compartment size and space limitations. Figure 35 shows a plan view of the mock-up configuration for the Equipment Operation task detailing the overall dimensions.

The general compartment configuration allowed adequate room for performance of all task maneuvers. However, subject-equipment interactions were undesirable for certain aspects of the task. While working at the equipment module cabinet (EMC) the subject's body and leg motion unknowingly activated a number of the controls on the G+N display cabinet. The placement of the chair restraint component increased the problem of the subject-equipment interactions. Movement between the work table and the EMC was hampered and combined operation at the work table and the G+N console could only be efficiently accomplished when seated in the restraint chair. The chair-seat belt restraint component, however, did not prove completely useful due to the space requirements even though it proved to be a very adequate restraint mode for extended work periods at the display console and work table. Although the chair height was adjustable, the maximum useful height was inadequate with respect to the display console and work table. The optimum level appeared to require the chair seat to be at least five inches higher.

The small compartment afforded positive body interactions which aided the subject in maintaining a stationary position. When working at the EMC the subject used a combination of the available handholds, the CSU side panel, and the bulkhead wall to maintain his position. At no time did the subject require the entire height of the compartment for any operation or movement. The ceiling was subsequently lowered 6 inches, to 6 ft 6 in. for an additional task run and this lowered ceiling height did not affect task performance. It appeared that the reduced ceiling height afforded additional advantages by permitting pressure walking between surfaces.

Although the compartment configuration for the Equipment Operation task is considered less than adequate for long term operations and for rapid critical operations, estimates of optimum work area size have been made from the analysis of the task performance. Table XXII lists the measured space envelop required for the major task maneuvers of the Equipment Operation task. The envelop was obtained by measuring movement in the x-y plane, compartment height and width, from the film record. Movement in the transverse of z plane was made by visual estimate. Parallax corrections were made analytically.

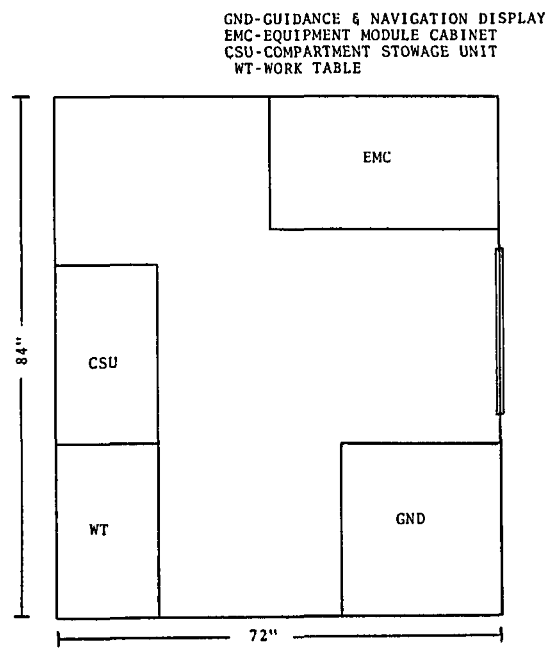


FIGURE 35 - PLAN VIEW OF EQUIPMENT OPERATION COMPARTMENT

The placement of the various equipment units in the compartment was not intended to achieve the most efficient task performance, but was intended to emphasize and evaluate the human factors interactions during the performance of Equipment Operation. It was noted

TABLE XXII

EFFECT OF EQUIPMENT OPERATION MANEUVERS ON REQUIRED SPACE ALLOCATIONS

MANEUVERS	POSITION	ENVELOP (FT) X	Y	Z	VOLUME (CU FT)
MODULE REPAIR	WORK TABLE	3.2	6.0	2.5	47.5
WRITING	WORK TABLE	3.2	6.0	2.5	47.7
MODULE REPAIR	EMC	3.3	4.3	2.9	42.1
DISPLAY SETUP (SEATED)	CONSOLE	4.0	5.0	3.0	60.0
DISPLAY SETUP (STANDING)	CONSOLE	3.0	6.0	3.0	54.0

that the positioning of the CSU and work table opposite the G+N display console provided easy access to support items such as data board, photographic gear, and miscellaneous items which generally support a systems control operation. Such a control room console configuration appears to have two desirable features in that it is compact and at the same time efficient.

Conclusions.--The fixed handholds proved a very efficient restraint for all operations of the Equipment Operations task. When working with both hands at the work table, the toe traps provided the necessary stabilization to maintain controlled body position. In work positions at the EMC, where both hands were occupied, the proximity of the compartment walls provided a certain amount of positioning restraint.

Handholds also provided the best means of locomotion. When used in conjunction with the soaring mode, the handholds provided body positioning as well as definite points of contact when soaring from one position to another.

Initial evaluations showed that other restraints were adequate for maintaining body position for the control panel tasks and work table operations. The chair-seat belt restraint component was very adequate for extended seated operations at the G+N display. However, the chair configuration limited the working space of the

compartment. A folding chair configuration, which could be stowed when not in use, should prove to be an optimum design compromise.

The positive foot restraints also performed adequately but, since the toe traps provide the necessary restraint without the extra energy needed to attach the heel portion of the positive foot restraint, they appear to be a better choice for use at the work table because they are more efficient. Operations at the G+N display console were performed easily using only handholds to maintain body position. Precise hand operations involving small parts manipulation at the work table and EMC were also performed easily. At the EMC, the subject used a combination of handholds and body contact in the close quarters of the EMC and compartment walls. This provided a very stable position for working and compared favorably to the stability provided by the handhold and toe trap combination restraint mode at the work table working position.

The most difficult maneuver of the Equipment Operation task was photographing the G+N display after the control setup task. No specialized restraints were provided for this maneuver and there were no readily available protuberances that could be used. Also, the photographic maneuver required two hands and thus only the legs were available for maintaining position. The subject's main difficulty was in maintaining his position when sighting the control panel through the camera. Since this was the only critical maneuver for which restraint aids were not available, it appears that the reliance on compartment protuberances and equipment as a very necessary part of the overall restraint system and locomotion system is a desirable attribute in equipment design.

Cargo Handling and Stowage

One of the key elements of long duration missions involving space stations will be the transfer and stowage of cargo containers. A simulation-test was performed to evaluate the human factors aspects of transporting and stowing multiple individual cargo containers. The simulation was performed in two of the standard compartment elements developed for the General and Housekeeping tasks. These compartments measured 84" x 84" x 72" and were located adjacent to one another separated by a circular hatchway. The simulated cargo containers consisted of 9 neutrally buoyant, cylindrical gas bottles.

The cargo was initially stowed in a nested configuration on the floor of one of the compartments. The containers were placed one upon another in a pyramid configuration, captured by a strap which retained the containers to the floor. The stowage rack was located on the far wall of the second compartment. The stowage rack consisted of a box-like receptacle with 9 cells. Each cell was large enough to accept one cylinder and support the cylinder along its length. A linear gas connector manifold was located directly below

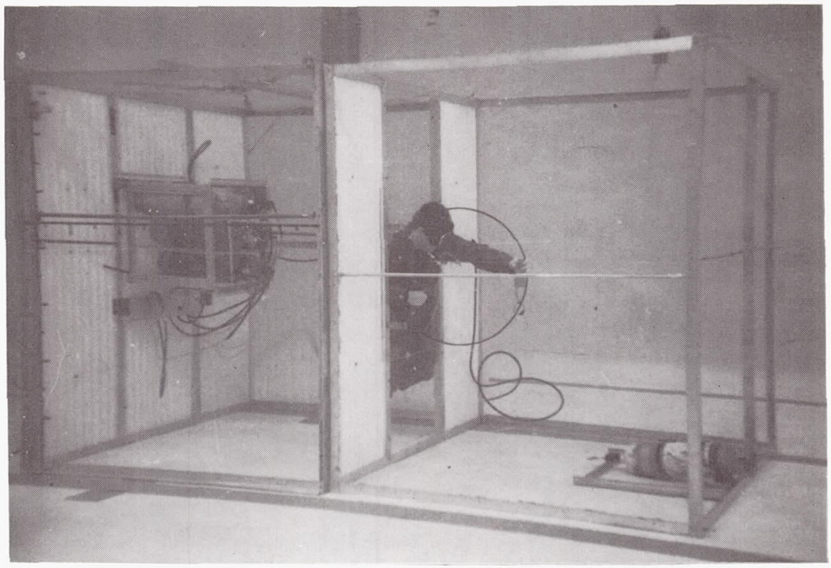
the stowage structure. Figure 36 shows the mock-up configuration of the Cargo Handling and Stowage simulation. Upon completion of the stowage of each individual cargo cylinder, the subject was required to effect the gas connection from the manifold to the rack.

The primary emphasis of the Cargo Handling and Stowage simulation was to determine the effect of locomotion aids and restraints on the ability of the subject to perform a serial stowage of the 9 cylindrical components. As a result of a preliminary evaluation, two primary locomotion modes were incorporated into the simulation. These were: (1) the combined use of soaring and strategically located handholds and (2) the use of a continuous handrail locomotion aid.

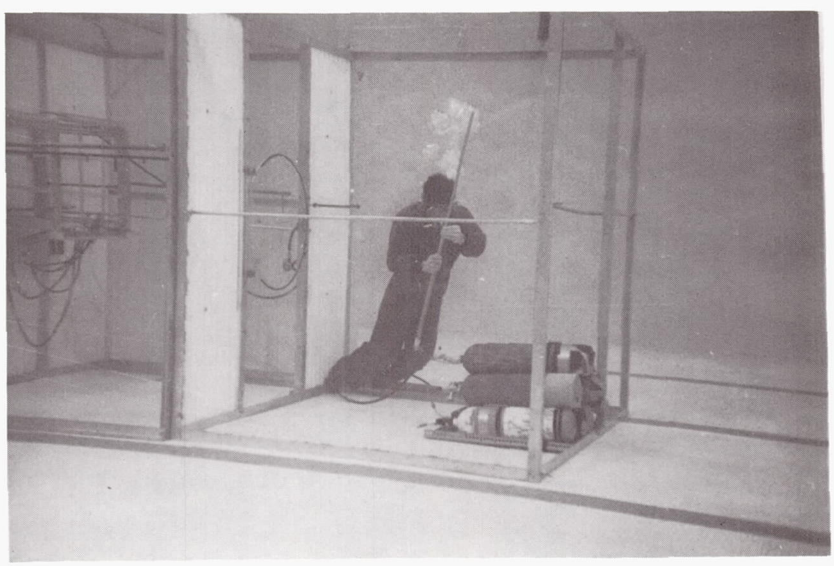
Preliminary restraint and locomotion aid evaluation.--These locomotion aid modes were determined as a result of the preliminary restraint and locomotion aid evaluation test run on the Cargo Handling sequence. The preliminary evaluation was performed in a manner similar to those performed for the General and Housekeeping and Equipment Operation tasks. There were 8 restraint modes evaluated for the Cargo Handling task: chair and seat belt, positive foot restraint, toe traps, handhold-handrail, waist tether (2), waist tether (1), velcro sandals, and no restraint. There were 4 locomotion aids evaluated for the Cargo Handling task: handrail, hand--holds, velcro sandals, and soaring. Preliminary restraint evaluations were made by performing one full tank transfer run for each different restraint system being evaluated. Preliminary locomotion evaluations were made by using the various locomotion systems being evaluated for 2 runs each (i.e., 2 complete tank transfers).

An evaluation matrix was compiled which included the critical task elements of the Cargo Handling and Stowage sequence. The preliminary evaluation matrix for the Cargo Handling and Stowage sequence is given in Table XXIII. The evaluation of the restraints and locomotion aids for Cargo Handling included 7 subtask elements in which restraint aids could be evaluated, and 5 subtask elements in which the locomotion aids could be evaluated. For example, the subtask element of unstowing the tank from the floor of the compartment entailed generally the use of restraints only since the subtask element was completely performed without movement. However, the transfer to hatch subtask element was one in which the locomotion aids could be evaluated.

All of the restraints and locomotion aids originally conceived to be evaluated during the contract were evaluated during the preliminary run of the Cargo Handling sequence. Only one of the restraint and locomotion aid candidates that were originally conceived in the contract proved to be completely incompatible with the Cargo Handling task. The adjustable chair restraint system was incompatible with the Cargo Handling sequence since no portion of the Cargo Handling sequence allowed fixed operations which were



OVERALL COMPARTMENT VIEW



TANK STORAGE COMPARTMENT

FIGURE 36 - MOCKUP CONFIGURATION FOR CARGO HANDLING SIMULATION

TABLE XXIII EVALUATION MATRIX FOR CARGO HANDLING

	RESTRAINTS								MOTION AIDS			
	VELCRO FOOT RESTRAINTS	HANDHOLDS	TETHERS (2)	TETHER (1)	CHAIR	POSITIVE FOOT RESTRAINTS	TOE TRAPS	NO RESTRAINTS	HANDRAILS	HANDHOLDS	SOARING	VELCRO FOOT RESTRAINTS
STAGE	2	4	1	2	1	2	3	1	N	N	N	N
UNSTOW TANK	2	4	1	1	1	2	3	1	N	N	N	N
TO HATCH	N	N	N	N	N	N	N	N	2	3	3	0
OPEN HATCH	2	3	0	0	0	0	0	1	N	N	N	N
THROUGH HATCH	N	N	N	N	N	N	N	N	2	4	3	0
CLOSE HATCH	2	3	0	0	0	0	0	1	N	N	N	N
TO TANK RACK	N	N	N	N	N	N	N	N	2	3	3	2
STOW TANK	2	4	2	2	1	2	3	1	N	N	N	N
CONNECTION	2	4	1	2	1	2	3	1	N	N	N	N
TO HATCH	N	N	N	N	N	N	N	N	2	3	3	2
OPEN HATCH	2	3	0	0	0	0	0	1	N	N	N	N
EXIT HATCH	N	N	N	N	N	N	N	N	2	4	3	0
TO TIEDOWN RACK	N	N	N	N	N	N	N	N	2	3	3	2
RATING (0-100)	50	89	18	25	14	29	43	25	50	83	75	25

N - NOT APPLICABLE

most compatible with the chair element. The results of the preliminary evaluation of the Cargo Handling sequence showed that the handhold-handrail restraint aid was the most useful for the general performance of the total Cargo Handling and Stowage sequence.

Other potentially useful candidate restraint elements were the velcro sandals and the toe trap elements. A combination of soaring and handholds appeared to be the most efficient locomotion aid. However, since the handrail locomotion aid was placed around the compartment perimeter for the preliminary evaluation, it was decided to reevaluate the handrail as a locomotion aid in the final task run, using a center handrail. This center portable handrail was evaluated against the soaring-handrail combination locomotion aid. Two complete runs were made with 9 tank transfers per run. Three variations in the method of tank transfer were employed in both of the final runs. The tank was carried by its end valve for the first 7 tank transfers. On the eighth tank transfer, the unit was carried under the right arm. On the ninth tank transfer, the unit was carried by a handhold secured to the center of the cylinder.

Task analysis.--Two distinct series of cargo transfers were performed to determine the most effective restraint and locomotion aids to be used in subsequent test runs. One series was conducted employing a combination of soaring and handholds as the primary locomotion mode. A second series was conducted employing a centrally located handrail as the locomotion mode. Each series consisted of individually transferring the 9 tanks from one compartment to the other, placing the cargo component in the stowage rack, and connecting the air manifold line. The subject was instructed to hold the tank in any manner he preferred for the transfer of the first 7 cargo tanks. To evaluate alternate methods of handling cargo, he was instructed to carry the eighth tank under his arm and the ninth tank by means of a folding handle attached on its side. The detailed performance analysis for these two series are given in Tables XXIV and XXV. The following description of the major aspects of each series is correlated to the picture sequences, Figures 37 through 40.

Soaring and handholds: The subject started the soaring-handhold series staged in front of the tank tiedown rack with his back to the adjoining compartment. He loosened the belt type tank restraint with his left hand while withdrawing the first tank with his right, Figure 37a. Stability was maintained by available handholds. The subject maintained his position by securing a handhold on the tank that was to be withdrawn and by holding the tank retention straps. He restrained himself by holding the tank restraint tiedown strap after withdrawing the tank. The subject gained added stability by placing his feet at the base of the wall behind him, thus preventing his body from moving backward. The subject moved to the compartment hatch holding the tank in his right hand. The

TABLE XXIV.--PERFORMANCE ANALYSIS OF CARGO HANDLING (SOARING-HANDHOLD) †

SUBTASK ELEMENT	DESCRIPTION	TIME SEC.	COMMENTS
UNSTOW TANK NO. 1.	RELEASES TANK TIEDOWN STRAP. REMOVES TANK NO.1. CAPTURES FREE TANKS AND SECURES TIEDOWN STRAP.	40	SUBJECT CARRIES TANKS 1 THROUGH 7 BY HOLDING VALVE ON END OF TANK WITH ONE HAND. HE REMOVES TANK FROM RACK BY LOOSENING STRAP AND SLIDING TANK OUT. HE DOES NOT AT ANY TIME DURING THIS TASK RELEASE THE TIEDOWN STRAP.
TRANSFER TANK NO. 1 TO MANIFOLD RACK.	MOVES TO HATCH. OPENS HATCH. TRANSFERS THROUGH. CLOSES HATCH. MOVES TO MANIFOLD.	45	SUBJECT CARRIES TANK NO. 1 WITH HIS LEFT HAND AND ENTERS HATCH FEET FIRST
STOW AND ACTIVATE TANK NO. 1.	INSERTS TANK NO. 1 IN MANIFOLD RACK. ATTACHES MANIFOLD HOSE COUPLING.	25	SUBJECT USES VERTICAL HANDHOLD ON LEFT SIDE OF MANIFOLD RACK TO MAINTAIN POSITION WHILE INSERTING TANK WITH RIGHT HAND.
RETURN TO TANK TIEDOWN RACK.	MOVES TO HATCH. OPENS HATCH. TRANSFERS THROUGH HATCH. CLOSES HATCH. MOVES TO TANK TIEDOWN RACK.	40	SUBJECT MOVES THROUGH HATCH HEAD FIRST.
UNSTOW TANK NO. 2.	RELEASES TANK TIEDOWN STRAP. REMOVES TANK NO.2. CAPTURES FREE TANKS AND SECURES TIEDOWN STRAP.	15	SUBJECT USES TANKS IN RACK AS HANDHOLDS WHILE SLIDING TANK NO. 2 OUT OF RACK.
TRANSFER TANK NO. 2 TO MANIFOLD RACK.	MOVES TO HATCH. OPENS HATCH. TRANSFERS THROUGH. CLOSES HATCH. MOVES TO MANIFOLD.	45	SUBJECT'S PROCEDURE FOR SOARING IS TO REACH AS FAR AS POSSIBLE IN THE DIRECTION OF HIS INTENDED POINT OF CONTACK WHILE MAINTAINING A HANDHOLD POSITION. HE WOULD THEN PUSH OFF

† ref. figs. 37, 38, 39

TABLE XXIV.--PERFORMANCE ANALYSIS OF CARGO HANDLING (SOARING-HANDHOLD) - CONTINUED

SUBTASK ELEMENT	DESCRIPTION	TIME SEC.	COMMENTS
			WITH ENOUGH FORCE TO REACH HIS NEXT HANDHOLD POSITION.
STOW AND ACTIVATE TANK NO. 2.	INSERTS TANK NO. 2 IN MANIFOLD RACK. ATTACHES MANIFOLD HOSE COUPLING.	15	
RETURN TO TANK TIEDOWN RACK.	MOVES TO HATCH. OPENS HATCH. TRANSFERS THROUGH HATCH. CLOSES HATCH. MOVES TO TANK TIEDOWN RACK.	30	SUBJECT RETURNS THROUGH HATCH HEAD FIRST.
UNSTOW TANK NO. 3.	RELEASES TANK TIEDOWN STRAP. REMOVES TANK NO.3. CAPTURES FREE TANKS AND SECURES TIEDOWN STRAP.	20	SUBJECT AGAIN USES ONE OF THE REMAINING TANKS IN THE RACK AS A HANDHOLD WHILE REMOVING TANK NO. 3.
TRANSFER TANK NO. 3 TO MANIFOLD RACK.	MOVES TO HATCH. OPENS HATCH. TRANSFERS THROUGH. CLOSES HATCH. MOVES TO MANIFOLD.	50	SUBJECT MOVES THROUGH HATCH FEET FIRST. HE CARRIES THE TANK IN HIS RIGHT HAND HOLDING THE VALVE AND CONNECTOR HOSE.
STOW AND ACTIVATE TANK NO. 3.	INSERTS TANK NO. 3 IN MANIFOLD RACK. ATTACHES MANIFOLD HOSE COUPLING.	15	SUBJECT INSERTS TANK WITH HIS RIGHT HAND. HE USES HIS LEFT HAND TO MAINTAIN A HANDHOLD ON THE MANIFOLD RACK.
RETURN TO TANK TIEDOWN RACK.	MOVES TO HATCH. OPENS HATCH. TRANSFERS THROUGH HATCH. CLOSES HATCH. MOVES TO TANK TIEDOWN RACK.	30	SUBJECT TRANSFERS THROUGH HATCH HEAD FIRST.

TABLE XXIV.--PERFORMANCE ANALYSIS OF CARGO HANDLING (SOARING-HANDHOLD) - CONTINUED

SUBTASK ELEMENT	DESCRIPTION	TIME SEC.	COMMENTS
UNSTOW TANK NO. 4.	RELEASES TANK TIEDOWN STRAP. REMOVES TANK NO.4. CAPTURES FREE TANKS AND SECURES TIEDOWN STRAP.	15	SUBJECT UNSTOWS TANK NO. 4 FROM A POSITION BESIDE THE TANK RACK. HE USES HIS RIGHT HAND TO PULL THE TANK OUT OF THE RACK BY ITS VALVE AND CONNECTOR.
TRANSFER TANK NO. 4 TO MANI-FOLD RACK.	MOVES TO HATCH. OPENS HATCH. TRANSFERS THROUGH. CLOSES HATCH. MOVES TO MANIFOLD.	25	SUBJECT HOLDS TANK IN RIGHT HAND UN-TIL HE MOVES THROUGH HATCH. HE THEN TRANSFERS HANDS SO THAT HIS RIGHT HAND WILL BE FREE TO CLOSE THE HATCH. HE MOVES THROUGH THE HATCH FEET FIRST
STOW AND ACTI-VATE TANK NO. 4.	INSERTS TANK NO. 4 IN MANIFOLD RACK. ATTACHES MANIFOLD HOSE COUPLING.	15	SUBJECT TRANSFERS TANK BACK TO RIGHT HAND AND INSERTS TANK IN MANIFOLD RACK. HE USES LEFT HAND TO MAINTAIN BODY POSITION.
RETURN TO TANK TIEDOWN RACK.	MOVES TO HATCH. OPENS HATCH. TRANSFERS THROUGH HATCH. CLOSES HATCH. MOVES TO TANK TIEDOWN RACK.	25	SUBJECT MOVES THROUGH HATCH HEAD FIRST.
UNSTOW TANK NO. 5.	RELEASES TANK TIEDOWN STRAP. REMOVES TANK NO.5. CAPTURES FREE TANKS AND SECURES TIEDOWN STRAP.	15	
TRANSFER TANK NO. 5 TO MANI-FOLD RACK.	MOVES TO HATCH. OPENS HATCH. TRANSFERS THROUGH. CLOSES HATCH. MOVES TO MANIFOLD.	25	SUBJECT MOVES THROUGH HATCH FEET FIRST.

TABLE XXIV.--PERFORMANCE ANALYSIS OF CARGO HANDLING (SOARING-HANDHOLD) - CONTINUED

SUBTASK ELEMENT	DESCRIPTION	TIME SEC.	COMMENTS
STOW AND ACTIVATE TANK NO. 5.	INSERTS TANK NO. 5 IN MANIFOLD RACK. ATTACHES MANIFOLD HOSE COUPLING.	20	
RETURN TO TANK TIEDOWN RACK.	MOVES TO HATCH. OPENS HATCH. TRANSFERS THROUGH HATCH. CLOSES HATCH. MOVES TO TANK TIEDOWN RACK.	15	SUBJECT MOVES THROUGH HATCH HEAD FIRST.
UNSTOW TANK NO. 6.	RELEASES TANK TIEDOWN STRAP. REMOVES TANK NO.6. CAPTURES FREE TANKS AND SECURES TIEDOWN STRAP.	10	
TRANSFER TANK NO. 6 TO MANIFOLD RACK.	MOVES TO HATCH. OPENS HATCH. TRANSFERS THROUGH. CLOSES HATCH. MOVES TO MANIFOLD.	35	SUBJECT MOVES THROUGH HATCH FEET FIRST.
STOW AND ACTIVATE TANK NO. 6.	INSERTS TANK NO. 6 IN MANIFOLD RACK. ATTACHES MANIFOLD HOSE COUPLING.	15	SUBJECT USES COMPARTMENT FLOOR AS RESTRAINT BY PUSHING DOWN WITH A LEFT HANDHOLD ON MANIFOLD RACK TO MAINTAIN TRACTION. HE STOWS AND ACTIVATES THE TANK IN THIS POSITION.
RETURN TO TANK TIEDOWN RACK.	MOVES TO HATCH. OPENS HATCH. TRANSFERS THROUGH HATCH. CLOSES HATCH. MOVES TO TANK TIEDOWN RACK.	15	SUBJECT MOVES HEAD FIRST THROUGH HATCH.

TABLE XXIV.--PERFORMANCE ANALYSIS OF CARGO HANDLING (SOARING-HANDHOLD) - CONTINUED

SUBTASK ELEMENT	DESCRIPTION	TIME SEC.	COMMENTS
UNSTOW TANK NO. 7.	RELEASES TANK TIEDOWN STRAP. REMOVES TANK NO.7. CAPTURES FREE TANKS AND SECURES TIEDOWN STRAP.	10	
TRANSFER TANK NO. 7 TO MANI-FOLD RACK.	MOVES TO HATCH. OPENS HATCH. TRANSFERS THROUGH. CLOSES HATCH. MOVES TO MANIFOLD.	35	SUBJECT MOVES FEET FIRST THROUGH HATCH.
STOW AND ACTI-VATE TANK NO. 7.	INSERTS TANK NO. 7 IN MANIFOLD RACK. ATTACHES MANIFOLD HOSE COUPLING.	10	SUBJECT USES WALL AS A RESTRAINT AID BY PLACING HIS FOOT AND SHOULDER ON WALL WHEN INSERTING TANK.
RETURN TO TANK TIEDOWN RACK.	MOVES TO HATCH. OPENS HATCH. TRANSFERS THROUGH HATCH. CLOSES HATCH. MOVES TO TANK TIEDOWN RACK.	25	SUBJECT MOVES HEAD FIRST THROUGH HATCH.
UNSTOW TANK NO. 8.	RELEASES TANK TIEDOWN STRAP. REMOVES TANK NO.8. CAPTURES FREE TANK AND SECURES TIEDOWN STRAP.	10	SUBJECT CARRIES TANK NO. 8 WITH HIS ARM ENCIRCLING ITS DIAMETER. HE IS INSTRUCTED TO USE THIS VARIATION ON TANK NO. 8.
TRANSFER TANK NO. 8 TO MANI-FOLD.	MOVES TO HATCH. OPENS HATCH. TRANSFERS THROUGH. CLOSES HATCH. MOVES TO MANIFOLD.	35	SUBJECT MOVES FEET FIRST THROUGH HATCH, CARRYING THE TANK UNDER HIS RIGHT ARM. HE TRANSFERS THE TANK TO HIS LEFT ARM AFTER ENTERING THE TANK MANIFOLD COMPARTMENT.
STOW AND ACTI-VATE TANK NO. 8.	INSERTS TANK NO. 8 IN MANIFOLD RACK. ATTACHES MANIFOLD HOSE COUPLING.	20	AFTER CLOSING HATCH WITH HIS RIGHT HAND THE SUBJECT INSERTS TANK NO. 8 WITH HIS RIGHT HAND.

TABLE XXIV.--PERFORMANCE ANALYSIS OF CARGO HANDLING (SOARING-HANDHOLD) - CONTINUED

SUBTASK ELEMENT	DESCRIPTION	TIME SEC.	COMMENTS
RETURN TO TANK TIEDOWN RACK.	MOVES TO HATCH. OPENS HATCH. TRANSFERS THROUGH HATCH. CLOSES HATCH. MOVES TO TANK TIEDOWN RACK.	20	SUBJECT MOVES HEAD FIRST THROUGH HATCH.
UNSTOW TANK NO. 9.	RELEASES TANK TIEDOWN STRAP. REMOVES TANK NO.9. SECURES TIEDOWN STRAP.	15	SUBJECT CARRIES TANK NO. 9 USING FOLDING HANDLE.
TRANSFER TANK NO. 9 TO MANI-FOLD RACK.	MOVES TO HATCH. OPENS HATCH. TRANSFERS THROUGH. CLOSES HATCH. MOVES TO MANIFOLD.	35	SUBJECT MOVES FEET FIRST THROUGH HATCH CARRYING TANK BY HANDLE SIMILAR TO CARRYING A SUITCASE.
STOW AND ACTI-VATE TANK NO. 9.	INSERTS TANK NO. 9 IN MANIFOLD RACK. ATTACHES MANIFOLD HOSE COUPLING.	20	SUBJECT FOLDS HANDLE IN BUT STILL ENCOUNTERS SLIGHT DIFFICULTY WHEN INSERTING THE TANK.
RETURN TO TANK TIEDOWN RACK.	MOVES TO HATCH. OPENS HATCH. TRANSFERS THROUGH HATCH. CLOSES HATCH. MOVES TO TANK TIEDOWN RACK.	30	SUBJECT MOVES HEAD FIRST THROUGH HATCH. SUBJECT NOTES THAT HANDLE ON TANK PROVES VERY EFFICIENT.

TABLE XXV.--PERFORMANCE ANALYSIS OF CARGO HANDLING (CENTER HANDRAIL) †

SUBTASK ELEMENT	DESCRIPTION	TIME SEC.	COMMENTS
UNSTOW TANK NO. 1.	RELEASES TANK TIEDOWN STRAP. REMOVES TANK NO.1. CAPTURES FREE TANKS AND SECURES TIEDOWN STRAP.	20	SUBJECT CARRIES TANKS 1 THROUGH 7 BY HOLDING VALVE ON END OF TANK WITH ONE HAND. HE REMOVES TANK FROM RACK WITHOUT RELEASING TIEDOWN STRAP.
TRANSFER TANK NO. 1 TO MANIFOLD RACK.	MOVES TO HATCH. OPENS HATCH. TRANSFERS THROUGH. CLOSES HATCH. MOVES TO MANIFOLD.	20	SUBJECT CARRIES TANK NO. 1 WITH LEFT HAND WHILE USING RIGHT HAND TO MANEUVER ON HANDRAIL. HE ENTERS HATCH FEET FIRST.
STOW AND ACTIVATE TANK NO. 1.	INSERTS TANK NO. 1 IN MANIFOLD RACK. ATTACHES MANIFOLD HOSE COUPLING.	10	SUBJECT USES VERTICAL HANDRAIL ON TANK RACK TO MAINTAIN POSITION.
RETURN TO TANK TIEDOWN RACK.	MOVES TO HATCH. OPENS HATCH. TRANSFERS THROUGH HATCH. CLOSES HATCH. MOVES TO TANK TIEDOWN RACK.	25	SUBJECT ENTERS HATCH HEAD FIRST.
UNSTOW TANK NO. 2.	RELEASES TANK TIEDOWN STRAP. REMOVES TANK NO.2. CAPTURES FREE TANKS AND SECURES TIEDOWN STRAP.	10	SUBJECT REMOVES TANK FROM RACK WITHOUT RELEASING TIEDOWN STRAP.
TRANSFER TANK NO. 2 TO MANIFOLD RACK.	MOVES TO HATCH. OPENS HATCH. TRANSFERS THROUGH. CLOSES HATCH. MOVES TO MANIFOLD.	15	SUBJECT ENTERS HATCH FEET FIRST.
STOW AND ACTIVATE TANK NO. 2.	INSERTS TANK NO. 2 IN MANIFOLD RACK. ATTACHES MANIFOLD HOSE COUPLING.	10	SUBJECT USES FRONT AND SIDE BULKHEADS AS RESTRAINTS WHILE INSERTING THE TANK INTO RACK.

† ref. fig. 40

TABLE XXV.--PERFORMANCE ANALYSIS OF CARGO HANDLING (CENTER HANDRAIL) - CONTINUED

SUBTASK ELEMENT	DESCRIPTION	TIME SEC.	COMMENTS
RETURN TO TANK TIEDOWN RACK.	MOVES TO HATCH. OPENS HATCH. TRANSFERS THROUGH HATCH. CLOSES HATCH. MOVES TO TANK TIEDOWN RACK.	15	SUBJECT MOVES THROUGH HATCH HEAD FIRST.
UNSTOW TANK NO. 3.	RELEASES TANK TIEDOWN STRAP. REMOVES TANK NO.3. CAPTURES FREE TANKS AND SECURES TIEDOWN STRAP.	10	SUBJECT AGAIN SLIDES TANK FROM BENEATH STRAP WITHOUT RELEASING STRAP BUCKLE.
TRANSFER TANK NO. 3 TO MANIFOLD RACK.	MOVES TO HATCH. OPENS HATCH. TRANSFERS THROUGH. CLOSES HATCH. MOVES TO MANIFOLD.	20	SUBJECT MOVES THROUGH HATCH FEET FIRST.
STOW AND ACTIVATE TANK NO. 3.	INSERTS TANK NO. 3 IN MANIFOLD RACK. ATTACHES MANIFOLD HOSE COUPLING.	10	SUBJECT USES HATCH BULKHEAD AND TANK MANIFOLD RACK TO MAINTAIN POSITION.
RETURN TO TANK TIEDOWN RACK.	MOVES TO HATCH. OPENS HATCH. TRANSFERS THROUGH HATCH. CLOSES HATCH. MOVES TO TANK TIEDOWN RACK.	30	SUBJECT MOVES THROUGH HATCH HEAD FIRST.
UNSTOW TANK NO. 4.	RELEASES TANK TIEDOWN STRAP. REMOVES TANK NO.4. CAPTURES FREE TANKS AND SECURES TIEDOWN STRAP.	10	SUBJECT REMOVES TANK THE SAME AS TANKS 1-3.

TABLE XXV.--PERFORMANCE ANALYSIS OF CARGO HANDLING (CENTER HANDRAIL) - CONTINUED

SUBTASK ELEMENT	DESCRIPTION	TIME SEC.	COMMENTS
TRANSFER TANK NO. 4 TO MANIFOLD RACK.	MOVES TO HATCH. OPENS HATCH. TRANSFERS THROUGH. CLOSES HATCH. MOVES TO MANIFOLD.	35	SUBJECT ENTERS HATCH FEET FIRST. HE USES CENTER HANDRAIL AS A RESTRAINT AID TO OPEN THE HATCH.
STOW AND ACTIVATE TANK NO. 4.	INSERTS TANK NO. 4 IN MANIFOLD RACK. ATTACHES MANIFOLD HOSE COUPLING.	10	SUBJECT USES HATCH BULKHEAD AND CENTER HANDRAIL AS RESTRAINT AIDS.
RETURN TO TANK TIEDOWN RACK.	MOVES TO HATCH. OPENS HATCH. TRANSFERS THROUGH HATCH. CLOSES HATCH. MOVES TO TANK TIEDOWN RACK.	20	SUBJECT ENTERS HATCH HEAD FIRST.
UNSTOW TANK NO. 5.	RELEASES TANK TIEDOWN STRAP. REMOVES TANK NO.5. CAPTURES FREE TANKS AND SECURES TIEDOWN STRAP	10	SUBJECT REMOVES TANK AS BEFORE.
TRANSFER TANK NO. 5 TO MANIFOLD RACK.	MOVES TO HATCH. OPENS HATCH. TRANSFERS THROUGH. CLOSES HATCH. MOVES TO MANIFOLD.	15	SUBJECT ENTERS HATCH FEET FIRST. THE CENTER HANDRAIL IN THE MANIFOLD RACK APPEARS UNNECESSARY AS A LOCOMOTION AID BECAUSE OF THE CLOSE COMPARTMENT QUARTERS.
STOW AND ACTIVATE TANK NO. 5.	INSERTS TANK NO. 5 IN MANIFOLD RACK. ATTACHES MANIFOLD HOSE COUPLING.	10	

TABLE XXV.--PERFORMANCE ANALYSIS OF CARGO HANDLING (CENTER HANDRAIL) - CONTINUED

SUBTASK ELEMENT	DESCRIPTION	TIME SEC.	COMMENTS
RETURN TO TANK TIEDOWN RACK.	MOVES TO HATCH. OPENS HATCH. TRANSFERS THROUGH HATCH. CLOSES HATCH. MOVES TO TANK TIEDOWN RACK.	20	SUBJECT ENTERS HATCH HEAD FIRST.
UNSTOW TANK NO. 6.	RELEASES TANK TIEDOWN STRAP. REMOVES TANK NO.6. CAPTURES FREE TANKS AND SECURES TIEDOWN STRAP.	5	
TRANSFER TANK NO. 6 TO MANI-FOLD RACK.	MOVES TO HATCH. OPENS HATCH. TRANSFERS THROUGH. CLOSES HATCH. MOVES TO MANIFOLD.	20	FEET FIRST ENTRY.
STOW AND ACTI-VATE TANK NO. 6.	INSERTS TANK NO. 6 IN MANIFOLD RACK. ATTACHES MANIFOLD HOSE COUPLING.	15	
RETURN TO TANK TIEDOWN RACK.	MOVES TO HATCH. OPENS HATCH. TRANSFERS THROUGH HATCH. CLOSES HATCH. MOVES TO TANK TIEDOWN RACK.	15	HEAD FIRST ENTRY.
UNSTOW TANK NO. 7.	RELEASES TANK TIEDOWN STRAP. REMOVES TANK NO.7. CAPTURES FREE TANKS AND SECURES TIEDOWN STRAP.	10	
TRANSFER TANK NO. 7 TO MANI-FOLD RACK.	MOVES TO HATCH. OPENS AND TRANSFERS THROUGH. CLOSES HATCH. MOVES TO MANIFOLD.	15	HEAD FIRST ENTRY.

TABLE XXV.--PERFORMANCE ANALYSIS OF CARGO HANDLING (CENTER HANDRAIL) CONTINUED

SUBTASK ELEMENT	DESCRIPTION	TIME SEC.	COMMENTS
STOW AND ACTIVATE TANK NO. 7.	INSERTS TANK NO. 7 IN MANIFOLD RACK. ATTACHES MANIFOLD HOSE COUPLING.	10	
RETURN TO TANK TIEDOWN RACK.	MOVES TO HATCH. OPENS HATCH. TRANSFERS THROUGH HATCH. CLOSES HATCH. MOVES TO TANK TIEDOWN RACK.	15	FEET FIRST ENTRY.
UNSTOW TANK NO. 8.	RELEASES TANK TIEDOWN STRAP. REMOVES TANK NO. 8. CAPTURES FREE TANK AND SECURES TIEDOWN STRAP.	10	SUBJECT SECURES TANK UNDER HIS LEFT ARM BEFORE MOVING TO HATCH.
TRANSFER TANK NO. 8 TO MANIFOLD RACK.	MOVES TO HATCH. OPENS HATCH. TRANSFERS THROUGH. CLOSES HATCH. MOVES TO MANIFOLD.	20	SUBJECT CARRIES TANK UNDER HIS LEFT ARM AND USES HIS RIGHT HAND TO MANEUVER ALONG CENTER HANDRAIL.
STOW AND ACTIVATE TANK NO. 8.	INSERTS TANK NO. 8 IN MANIFOLD RACK. ATTACHES MANIFOLD HOSE COUPLING.	10	CONNECTION OF HOSE COUPLING APPEARS TO BE A TWO-HANDED OPERATION. SUBJECT USES ONE HAND TO HOLD TANK AND MANIFOLD RACK AS A RESTRAINT AND THE OTHER HAND TO ACTIVATE HOSE COUPLING.
RETURN TO TANK TIEDOWN RACK.	MOVES TO HATCH. OPENS HATCH. TRANSFERS THROUGH HATCH. CLOSES HATCH. MOVES TO TANK TIEDOWN RACK.	20	

TABLE XXV.--PERFORMANCE ANALYSIS OF CARGO HANDLING (CENTER HANDRAIL) - CONTINUED

SUBTASK ELEMENT	DESCRIPTION	TIME SEC.	COMMENTS
UNSTOW TANK NO. 9.	RELEASES TANK TIEDOWN STRAP. REMOVES TANK NO.9. SECURE TIEDOWN STRAP.	10	
TRANSFER TANK NO. 9 TO MANI-FOLD RACK.	MOVES TO HATCH. OPENS HATCH. TRANSFERS THROUGH. CLOSES HATCH. MOVE TO MANIFOLD.	15	SUBJECT USES HANDHOLD ON TANK NO. 9. THIS APPEARS TO BE THE BEST WAY TO EFFICIENTLY TRANSFER CARGO.
STOW AND ACTI-VATE TANK NO. 9.	INSERTS TANK NO. 9 IN MANIFOLD RACK. ATTACHES MANIFOLD HOSE COUPLING.	10	SUBJECT USES HATCH BULKHEAD AS RESTRAINT.
RETURN TO TANK TIEDOWN RACK.	MOVES TO HATCH. OPENS HATCH. TRANSFERS THROUGH HATCH. CLOSES HATCH. MOVES TO TANK TIEDOWN RACK.	15	SUBJECT ENTERS HATCH HEAD FIRST. TEST TIME ENDS AFTER SUBJECT CLOSES HATCH.

primary locomotion mode was soaring after pushoff from the tiedown position. He pushed away from the tank tiedown rack and then grasped the handle of the compartment hatch, Figure 37b.

Available handholds were used entensively when transferring through the hatch. The subject moved through the hatch feet first, with his left hand holding the rim of the door. When partially through the hatch, he turned to his right, Figure 37c, took the tank in his left hand, and completed his transfer through the hatch. This allowed his right hand to be free to stow his breathing apparatus before closing the hatch. He then closed the hatch with his free hand, Figure 37d.

The subject turned and was within easy reach of the tank stowage rack. He transferred the tank to his right hand and drew himself to the rack with his left hand. He inserted the tank into the stowage rack while maintaining this handhold, Figure 37e. He next grasped the stowage rack and secured the air manifold line which he connected to the valve of the transferred tank. He maintained his position throughout this procedure by holding onto the edge of the stowage rack, Figure 37f.

The subject returned to the adjoining compartment at the completion of the transfer of the tank. He unlatched the compartment hatch and pushed it open with his right hand. Grasping the rim of the hatch, he pulled himself through, entering the next compartment head first, Figure 37g. Completing his entry into the compartment, he turned and closed the hatch, after checking the position of his breathing apparatus, Figure 37h. This completed a full cycle of the transfer of a single tank using handholds and soaring as the locomotion aids and handholds as the restraint aid. The subject repeated this procedure for the next 6 cargo transfers. There were no apparent major differences in the subject's performance during the transfer of the first 7 tanks. In each case, the subject used the small valve end of the tank as the handhold.

The last two cargo transfers were performed in a different manner, to evaluate the optimum mode of handling and transporting a cargo component. During the eigth transfer, the tank was carried under the arm of the subject, and during the ninth transfer, the tank was carried by means of a handle attached to the side of the tank.

Cargo carried under arm - The subject removed the air tank from the floor stowage element in the same manner as the previous transfers. He immediately placed the tank under his right arm. The subject turned and grasped the handle of the compartment hatch with his left hand, Figure 38a, and drew himself up to the hatch. This differed from the soaring method of locomotion employed at this point in previous transfers. He opened the compartment hatch, Figure 38b, and proceeded to transfer to the next compartment. He used handholds at this point, holding the edge of the hatch as a

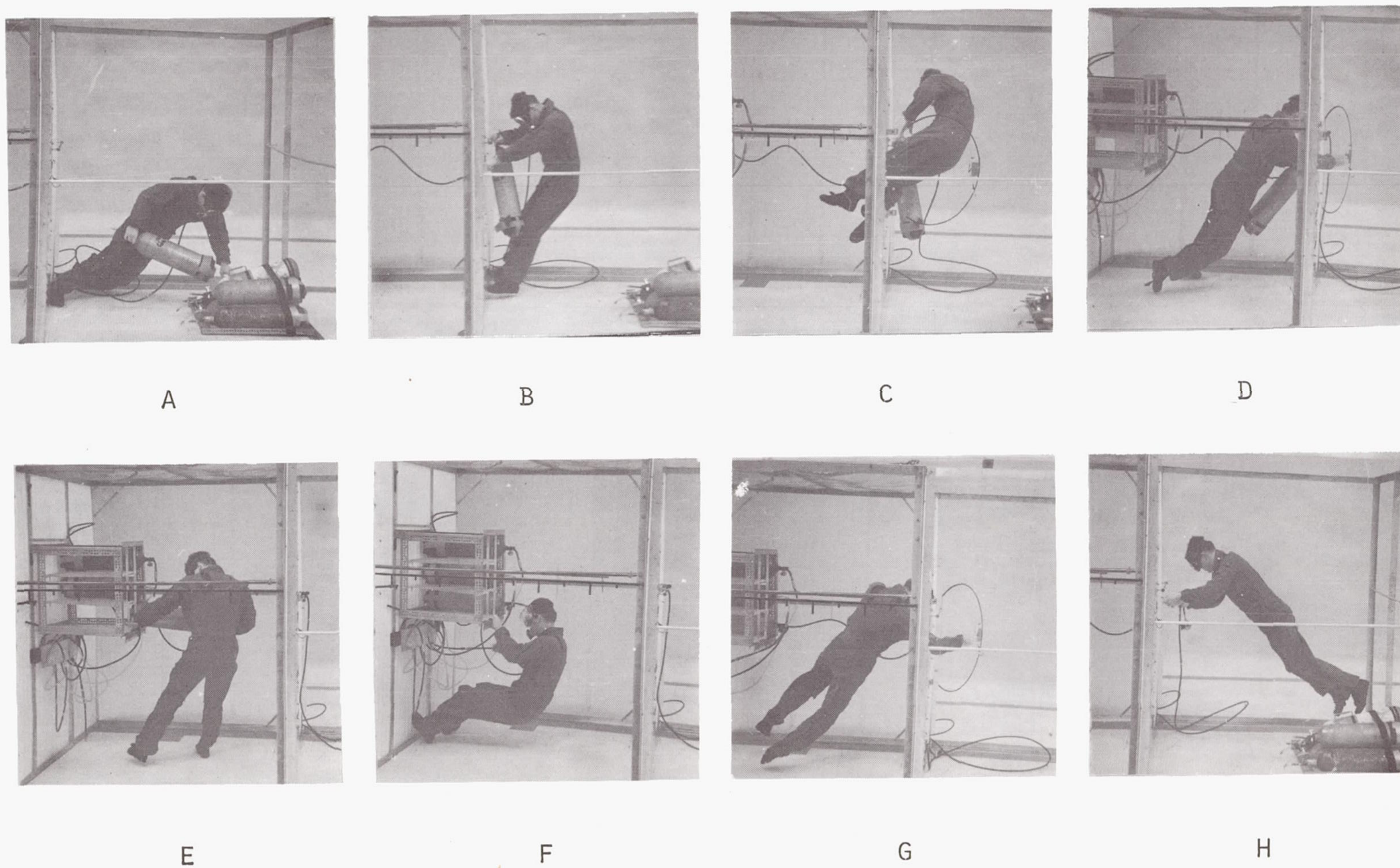


FIGURE 37 - CARGO HANDLING TASK SEQUENCE (A)

locomotion aid. He could use only his left hand to maintain stability, requiring full use of his right hand to hold the tank.

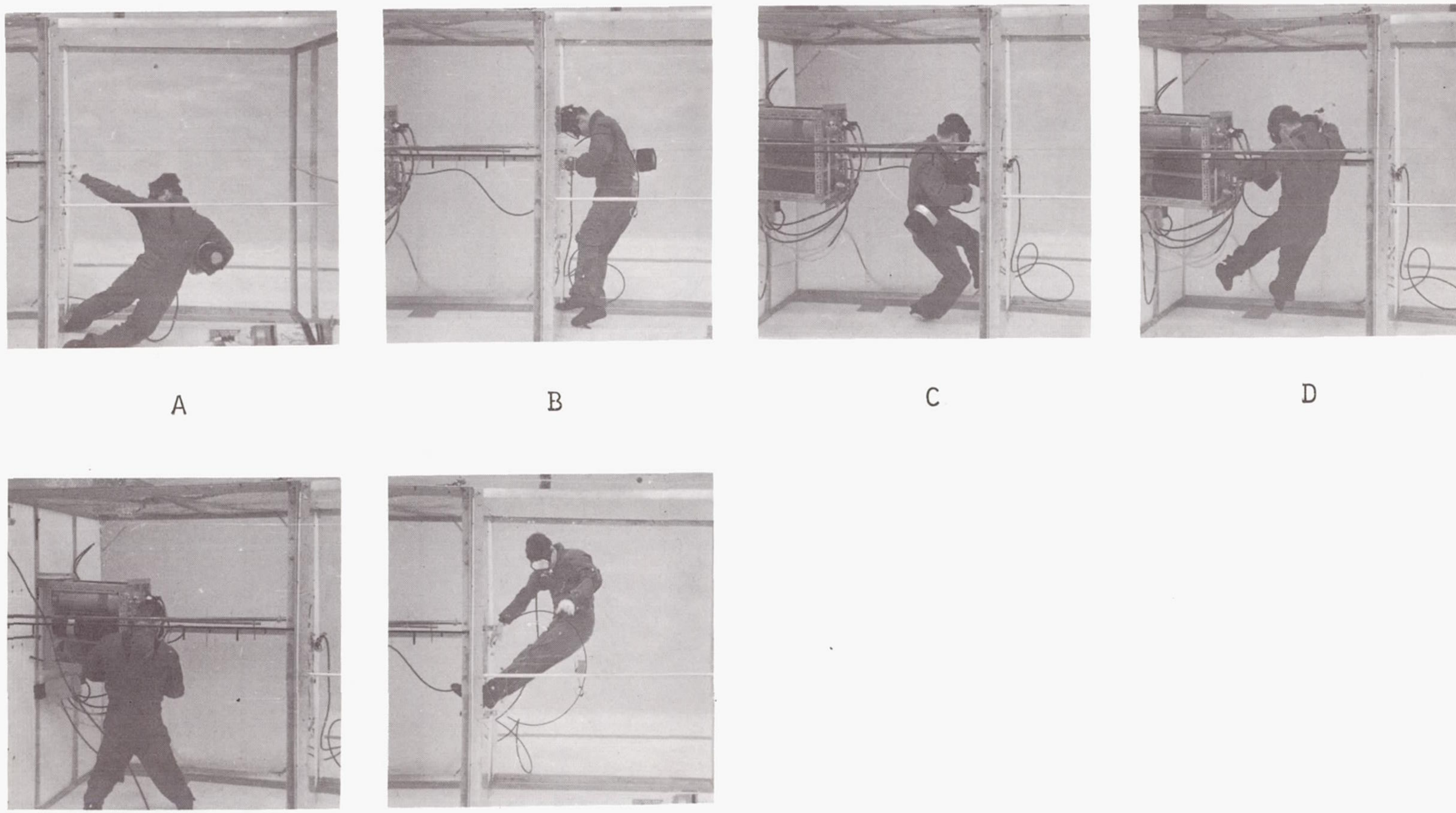
In previous transfers, the subject held the tank in his hand away from his body, allowing greater mobility when transferring through the hatch. This maneuverability was noticeably reduced when the tank was carried under the arm. The subject closed the hatch using his left hand, Figure 38c, and turned and grasped the tank stowage rack with his left hand. He then proceeded to stow the tank, Figure 38d. The remainder of the transfer cycle was performed in the same manner as in previous runs, Figures 38e and 38f.

Cargo carried by folding handle - The subject performed the ninth cargo transfer maneuver using an air tank with a handle attached to its side. He began the task by grasping the tank by its handle with his left hand, Figure 39a, releasing the tank restraint with his free hand. The subject pushed away from the tiedown rack, turned, and secured a handhold on the hatch handle. He opened the compartment hatch with his right hand, maintaining his hold on the tank with his left hand, Figure 39b. He used available handholds as his means of locomotion when passing through the hatch. He held the rim of the hatch with his right hand and passed through the hatch feet first.

Upon entering the next compartment, he turned and closed the hatch with his right hand, Figure 39c. With the tank still in his left hand, he positioned himself in front of the tank stowage rack. He accomplished this by pushing away from the base of the wall with his feet. The subject then brought the tank up to the stowage rack. With the end of the tank in the rack, he paused to fold the tank handle to the side, Figure 39d, and then continued the stowage in the normal manner. He attached the manifold air line, Figure 39e, and exited the stowage compartment, Figures 39f and 39g, as in the previous transfers. This concluded the transfer series employing the combination of soaring-handhold as the primary locomotion mode.

Handrail locomotion aid: An erectable handrail was mounted along the length of the two compartments for this second series of transfers to facilitate the movements of the subject. The handrail was supported at the bulkheads and was also to be used as a restraint aid when the subject found it to his advantage.

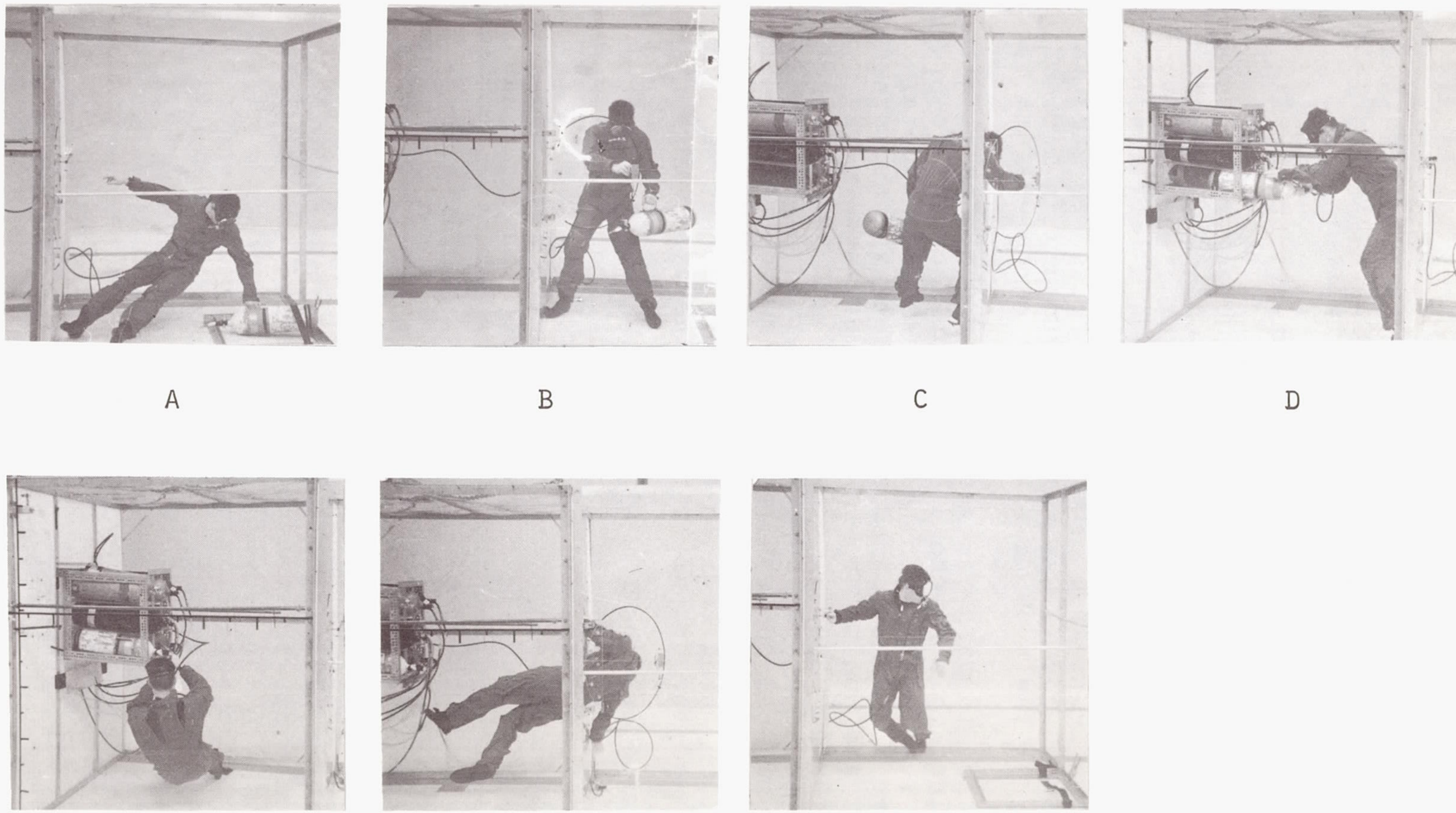
The subject began the test positioned in front of the tank tiedown rack with his back to the compartment hatch. He used both hands to loosen the tank restraint. He held the handrail as a restraint aid and pulled the tank from its stowed position, Figure 40a. The subject preferred to hold the tank by the valve stem as in the previous test. He used this same hold for each of the first 7 tanks. The subject held the tank in his right hand while grasping the handrail with his left. He pulled himself to an upright position and, using the handrail, moved to the compartment hatch. He opened



A B C D

E F

FIGURE 38 - CARGO HANDLING TASK SEQUENCE (B)



A B C D

E F G

FIGURE 39 - CARGO HANDLING TASK SEQUENCE (C)

the hatch with his left hand, Figure 40b. It is interesting to note that, while holding the tank, he was still able to restrain himself with his right hand, using the handrail.

Available handholds were used extensively when transferring through the compartment hatch. With his right hand on the handrail and his left hand holding the hatch door, the subject raised himself off the floor and through the hatch. The subject transferred through the hatch feet first. He turned to his right as he moved through the hatch, Figure 40c, and took the tank in his left hand. He then pulled the tank into the next compartment and closed the hatch door at the same time, Figure 40d. The subject turned to face the tank stowage rack. The handrail was not needed to aid in locomotion due to the proximity of the stowage rack to the hatch, Figure 40e.

The subject reached forward and secured a handhold on the stowage rack and maintained this handhold throughout the stowage procedure, Figure 40f. He reached beneath the stowage rack and obtained a manifold air line which he connected to the tank. He turned from the stowage rack and, using the handrail, returned to the compartment hatch. He opened the hatch with his right hand and pulled himself through, holding the edge of the hatch, Figures 40g and 40h. He entered the original compartment head first. He turned and, using the handrail as a restraint aid, closed the hatch door with his left hand. He then moved back to his starting position. This procedure was followed for transfers of containers one through seven.

Cargo carried under arm - The subject carried the tank under his arm for transfer No. 8. He removed the tank from its tiedown rack in the same manner as the previous transfer, by grasping the tank by the valve while restraining himself with the handrail. He placed the tank under his right arm and moved along the handrail to the compartment hatch. Transfer through the hatch was noticeably more difficult, as in the previous test with the tank under the arm.

The increased dimensions of the subject with the cargo under his arm restricted his mobility when moving through the hatch. The subject closed the hatch with his left hand. He transferred the tank to his left arm, leaving his right hand free to hold the handrail. He initiated his forward movement to the tank stowage rack with a slight pull on the handrail. When positioned in front of the stowage rack, the subject removed the tank from under his left arm and proceeded to stow it by holding the rack with his left hand and pushing the tank into place with his right hand. The manifold connection was made and the subject returned to the other compartment subsequent to the transfer of the final tank.

Cargo carried by folding handle - The subject transported the final tank by means of a handle attached to the side of the tank. The tank was unstowed from the tiedown rack by holding the handrail for restraint and grasping the tank by its handle. He transferred the

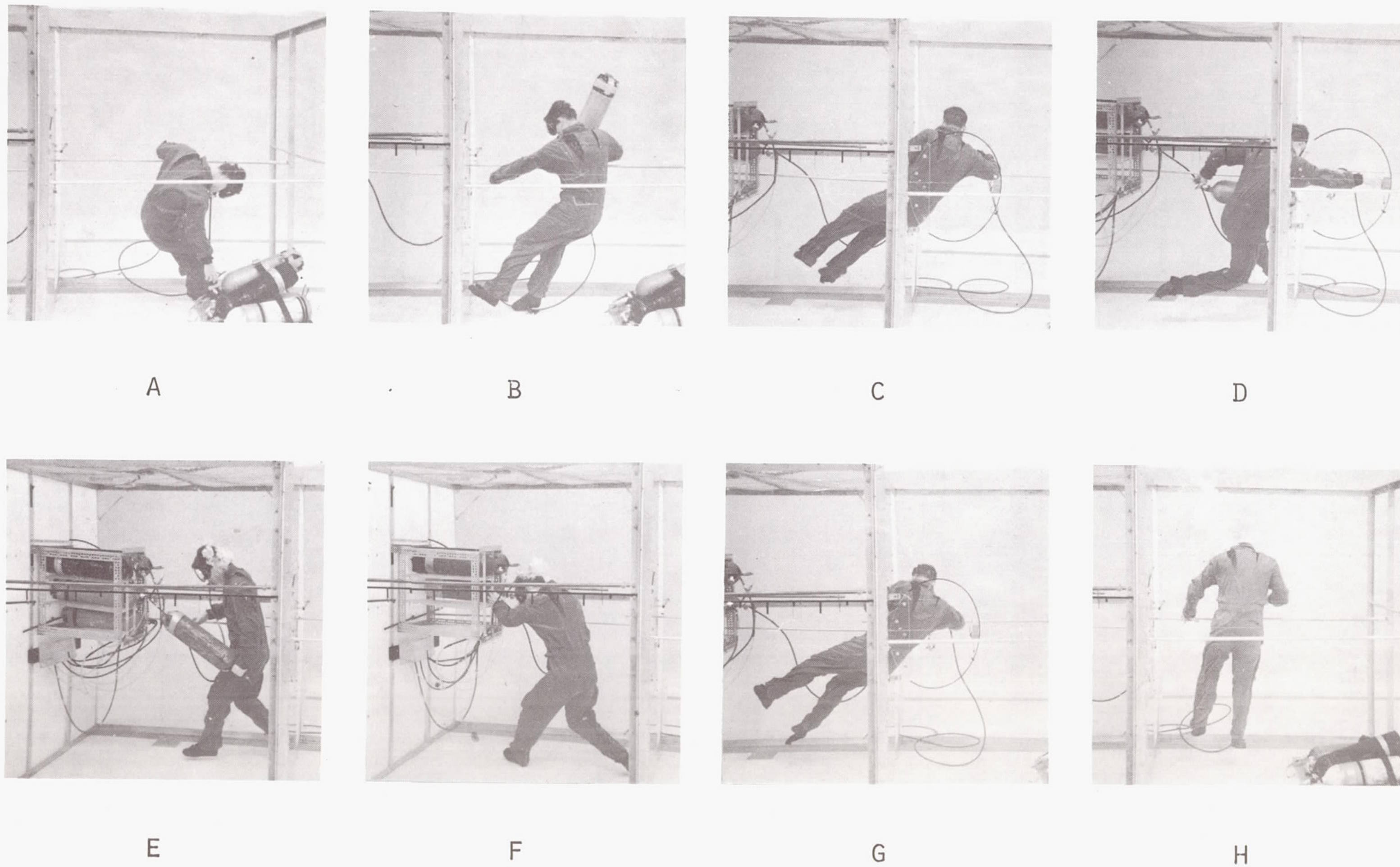


FIGURE 40 - CARGO HANDLING TASK SEQUENCE (D)

tank to the compartment hatch, holding the tank with his right hand. The subject opened the hatch with his left hand. He was able to use his right hand to restrain himself even though he was holding the tank in the same hand. He used the handrail for restraint when opening the hatch.

The subject transferred through the hatch feet first. The tank was transferred to his left hand as he moved through the hatch, allowing him to close the hatch door with his right. He turned and pushed away from the handrail to position himself for tank stowage. Taking the tank in his right hand, he grasped the stowage rack and inserted the tank. The subject returned to the compartment hatch after connecting the air manifold line using the handrail as a locomotion aid. He opened the hatch and entered the other compartment head first. The hatch was closed and the Cargo Transfer task terminated at this point.

Geometry, size, and space limitations of Cargo Handling and Stowage task.--Transfer of equipment and supplies through various size air locks, hatches, and space vehicle compartments is an immediate and continuing consideration for upcoming missions. Information on the spatial envelop, interactions of the compartment size and layout, and general shape and size of the resupply canisters is immediately required. The Cargo Handling and Stowage simulation was designed to determine the primary transfer and handling mode technique for cylindrical cargo components.

These components were made approximately neutrally buoyant to simulate the weightless effects of operation in a zero gravity environment. The dual 84" x 84" x 72" compartments were connected by a common bulkhead containing a one-way opening 32 inch diameter circular hatch. Measurement of the dimensional envelop and compartment volume utilized by the subject during the performance of the various versions of the Cargo Transfer simulation were made by the film analysis techniques previously described. The results of these measurements are given in Table XXVI.

Estimates of the space required for the transfer of cargo components between the several rack storage cells were also made. Table XXVII compares the space envelops for the cargo transfers using the center handrail and transfer using the combined soaring-handhold mode. Each of the cargo transfers with different locomotion aids was performed using three methods of carrying the cargo cylinder. These three methods of cylinder restraint, single hand on end valve, underarm, and center handhold, are also presented.

There was very little difference in the space required between the tank rack unstowage and the manifold stowage and connection maneuver. Differences which occurred were primarily due to the equipment placement. Comparison of the cargo transfer modes indicates that the most efficient method of transfer in terms of spatial

requirements was transfer involving cargo carried under the arm using the center handrail locomotion aid, even though the subject presented a larger cross section.

TABLE XXVI

SPACE ENVELOP AND COMPARTMENT VOLUME REQUIRED FOR CARGO HANDLING TASK

MANEUVER	POSITION	ENVELOP (FT)			VOLUME (CU FT)
		X	Y	Z	
CARGO CYLINDER REMOVAL	CARGO CYLINDER STOWAGE RACK	6.0	4.2	4.5	113.4
CARGO CYLINDER STOWAGE AND MANIFOLD CONNECTION	CARGO CYLINDER MANIFOLD RACK	6.0	6.0	4.2	151.2

The minimum time cargo transfer was also made with the center handrail as a locomotion aid. The cargo handling mode was the single handhold on the cylinder valve. The underarm restraint method ranked

TABLE XXVII

THE EFFECT OF LOCOMOTION MODE AND HANDLING MODE ON CARGO TRANSFER TASK

LOCOMOTION AID	CARGO HANDLING MODE	ENVELOP (FT)			CYCLE TIME (SEC)
		X	Y	Z	
CENTER PORTABLE HANDRAIL	SUBJECT PREFERENCE	*	6.4	3.4	79
	UNDERARM	*	6.4	3.2	80
	C. G. HANDHOLD	*	6.3	3.5	83
SOARING HANDHOLD COMBINATION	SUBJECT PREFERENCE	*	6.4	3.4	88
	UNDERARM	*	6.3	3.3	103
	C. G. HANDHOLD	*	6.4	3.6	82

* x dimension not given since it depends in this case on arbitrary choice.

second in terms of minimum time. A comparison of the times shows the underarm cargo restraint, with the center handrail locomotion aid to be the best means of cargo transfer.

Conclusions.--Initial restraint evaluations for the Cargo Handling and Transfer maneuver showed that the handholds were the most efficient restraint used. The velcro foot restraints were not effective due to the mass of the cargo cylinders. The inertia of the subject carrying the cylinder easily overcame the restraining influence of the velcro sandals.

The waist tethers were only applicable to fixed operations at the stowage and manifold areas and even then required time and energy to activate, which was unwarranted. It was also apparent from the preliminary evaluation run that a fixed position restraint was undesirable because of the gross station to station movement involved in cargo transfer. Therefore, fixed restraints did not prove to be necessary for the installation or removal of the cylinders. The subject observed that if larger forces were needed to insert the cylinder in the manifold receptacle, i.e., if the cylinder was any larger or if there was greater interference between the cylinder and the receptacle, that the positive foot restraints or some similar restraint would be needed.

Two locomotion modes were evaluated in the final runs, the center portable handrail and the combination soaring-handhold mode. Contrary to previous tasks, where soaring movements were restricted to extremely short distances and therefore the soaring mode proved efficient, analysis indicates that the center portable handrail was the most efficient locomotion aid for cargo transfer. The handrail traveled directly along the center of the compartment connecting the points at which the subject removed and installed the cargo cylinders. This was the shortest distance between the transfer terminals. Traveling along this path, the subject expended the least effort and gained the greatest efficiency.

The solid handrail provided greater positive restraint of body motion and allowed the subject to change his direction and attitude at will. During subject movement, the mass of the cargo cylinder affects the direction of motion and the handrail acts as a compensating factor allowing minor correction of path. These minor path corrections are not possible when the subject uses the pure soaring locomotion mode. Handhold placement was not found to be critical for locomotion. The subject normally grasped any protuberance that was stationary both in his transfer and stowage maneuvers. A handrail configuration around the perimeter of the compartment would serve as an adequate handhold locomotion aid. In this case, a single handrail encircling the cylinder stowage manifold would be ideal, allowing multiple handhold positions.

Of the three methods of cargo cylinder handling, cylinder transport under the subject's arm is the best mode when using the center handrail for locomotion. The subject's natural preference was to carry the cylinder by the end valve. The method was the most efficient mode when using soaring-handhold locomotion. The handhold

located at the center of balance of the cylinder did not prove to be a useful transfer restraint. This fact was interesting since visually the center of gravity handhold appeared adequate during on-site testing. It is felt that the efficiency of the underarm cylinder restraint mode is attributed to the increased control of the cylinder afforded the subject. With the cylinder firmly secured beneath the arm, tendency of the subject to follow other than a straight line path, as is the case with a loosely held cylinder, is minimized. It was noticed by both the test subject and observers that the single handhold cylinder and the center of balance handhold permitted free movement of the cylinder thus affecting efficiency of transfer.

The prime purpose of the Cargo Handling and Stowage was to evaluate transfer maneuvers. The cargo used was standard 71.2 cu ft air cylinders balanced to simulate zero gravity by releasing pressurized air until neutral buoyancy is achieved. The inherent preferential attitude tendencies were neutralized by adding ballast at various positions on the cylinder surface. Although slight instability was still exhibited in some of the cargo cylinders, the overall effect proved to be a valid representation of cargo transfer in a weightless condition.

Maintenance of Waste Management Subsystem

Maintenance of inflight hardware is an inevitable consequence of extended duration missions and, at times, will be performed within the confines of the space station in the compartment containing the equipment which is defective. Periodic preventative maintenance procedures will also necessitate on-site maintenance. In order to provide information about the astronaut's ability to perform maintenance functions on critical systems like waste management, the following simulation-test was performed. The simulation was performed in the standard compartment element developed for the General and Housekeeping tasks. This chamber measured 84" x 84" x 72" and was supplied with storage cabinets for the waste management systme hardware.

The waste management system components were supplied by NASA-LRC and constituted a prototype model of a waste management system designed for potential in-orbiting space stations. The subsystem provided for the collection, processing, and storage of waste products produced during a reference 60-day non-resupply mission. Figure 41 shows the waste management subsystem as utilized in the simulation. All of the components shown were used except the urine separator since it was determined that the immersion of the operational urine separator system was not warranted. The simulation-test comprised the partial assembly of the waste management system by the subject. Various components of the waste management subsystem were located in the storage racks provided.

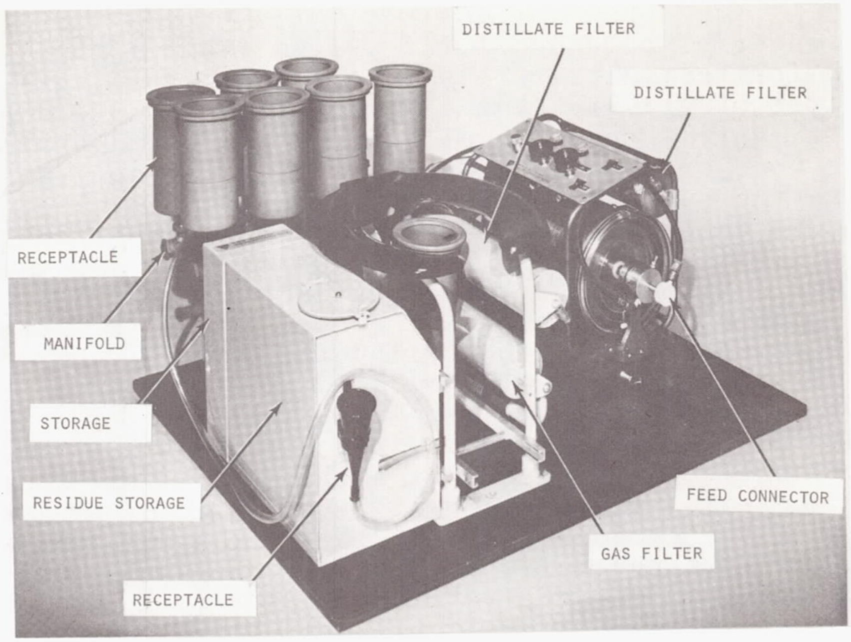


FIGURE 41 - WASTE MANAGEMENT SUBSYSTEM COMPONENTS USED IN THE SIMULATION

The experiments were performed at two simulated gravity levels in the water immersion mode and also were performed in a one gravity control mode. The main structure of the waste management subsystem was located on the floor of the compartment near the storage rack. An inspection routine was followed throughout the installation procedure, as summarized in NASA contract report N67-66124.

Preliminary restraint and locomotion aid evaluation.--Unlike the previous simulations, the preliminary restraint and locomotion evaluation of the Maintenance task was made using the complete subtask procedures developed for the final data run. This was done because the total task time interval was estimated to be only ten minutes. Also, the maneuvers contained in the Maintenance task were considered representative of the actual Maintenance tasks that would be performed in space. It was felt that a longer preliminary evaluation of the individual maneuvers was needed to evaluate the restraint and locomotion needs because the task was to be performed at various gravity levels.

The restraint modes evaluated in the Maintenance task were the following: chair and seat belt, positive foot restraints, toe traps, handholds, handrails, waist tether (2), waist tether (1), and velcro sandals. The locomotion aids evaluated in the Maintenance task were: perimeter handrail, velcro sandals, handholds, and soaring-handhold combination.

The restraints were evaluated at three primary positions in the mock-up. These were: the work area-WMS (waste management subsystem), the canister storage area, and the compartment storage unit area. These positions are shown in the plan view of Figure 42. The locomotion aids were evaluated for translation and maneuvering between these three primary work positions. Preliminary evaluation runs were performed at simulated zero gravity, simulated one-tenth gravity, and one gravity surface mode. Table XXVIII presents the evaluation matrix for the preliminary evaluation runs. It was observed that restraint and locomotion aids were particularly effective for the zero gravity runs.

The restraint aids and locomotion aids that proved to be most effective for the zero gravity run were also utilized where appropriate in the one-tenth and one gravity runs. Handholds and handhold-soaring combination were used in the final run of all gravity levels. Pictorial sequences of the final runs of the three gravity levels are given in Figures 43 through 45. The following task analysis discussion is correlated to these figures. A detailed analysis of the performance is given in Table XXIX.

Task analysis:

Zero gravity - The zero gravity simulation of the Maintenance task

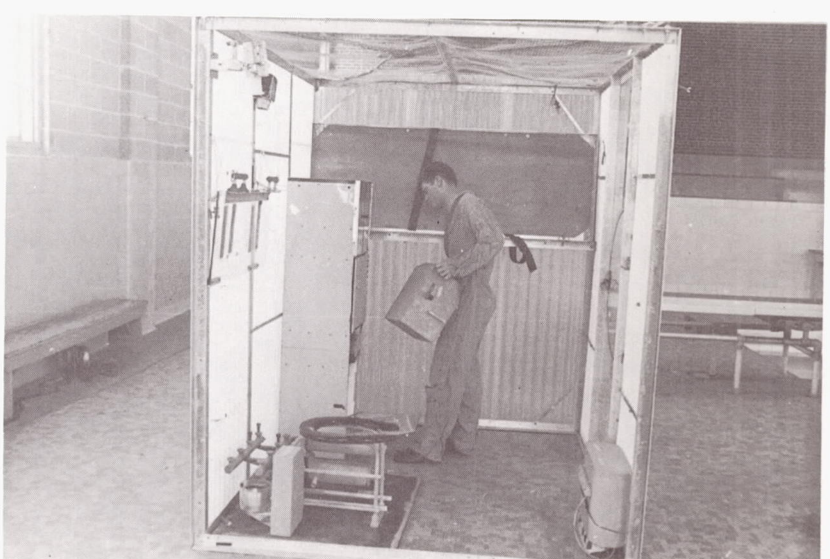


FIGURE 42 - MAINTENANCE TASK SIMULATION COMPARTMENT

TABLE XXVIII EVALUATION MATRIX FOR MAINTENANCE TASK

	RESTRAINTS								MOTION AIDS			
	VELCRO FOOT RESTRAINTS	HANDHOLDS	TETHERS (2)	TETHER (1)	CHAIR	POSITIVE FOOT RESTRAINTS	TOE TRAPS	NO RESTRAINTS	HANDRAILS	HANDHOLDS	SOARING	VELCRO FOOT RESTRAINTS
UNSTOW UNIT	2	4	1	1	1	2	2	1	N	N	N	N
TO WMS	N	N	N	N	N	N	N	N	2	3	3	2
ATTACH UNIT	1	4	1	1	0	1	1	1	N	N	N	N
TO CABINET	N	N	N	N	N	N	N	N	2	3	3	2
UNSTOW SEAT	2	4	1	1	1	2	2	1	N	N	N	N
ATTACH SEAT	1	4	1	1	0	1	1	1	N	N	N	N
UNSTOW PART A	2	4	1	1	1	2	2	1	N	N	N	N
ATTACH PART A	1	4	1	1	0	1	1	1	N	N	N	N
CONNECT LINE	1	4	1	1	0	1	1	1	N	N	N	N
UNSTOW PART B	2	4	1	1	1	2	2	1	N	N	N	N
ATTACH PART B	1	4	1	1	1	1	1	1	N	N	N	N
UNSTOW PART C	2	4	1	1	1	2	2	1	N	N	N	N
ATTACH PART C	1	4	1	1	0	1	1	1	N	N	N	N
UNSTOW AIRHOSE	2	4	1	1	1	2	2	1	N	N	N	N
ATTACH AIRHOSE	1	4	1	1	0	1	1	1	N	N	N	N
UNSTOW CANISTER	2	4	1	1	1	2	2	1	N	N	N	N
TO COMPARTMENT	N	N	N	N	N	N	N	N	2	3	3	2
STOW CANISTER	2	4	1	1	1	2	2	1	N	N	N	N
TO CABINET	N	N	N	N	N	N	N	N	2	3	3	2
UNSTOW CANISTER	2	4	1	1	1	2	2	1	N	N	N	N
ATTACH CANISTER	1	4	1	1	0	1	1	1	N	N	N	N
UNSTOW HOSE	2	4	1	1	1	2	2	1	N	N	N	N
ATTACH HOSE	1	4	1	1	0	1	1	1	N	N	N	N
UNSTOW URINAL	2	4	1	1	1	2	2	1	N	N	N	N
ATTACH URINAL	1	4	1	1	0	1	1	1	N	N	N	N
RATING (0-100)	38	100	25	25	14	38	38	25	50	75	75	50

N - NOT APPLICABLE

TABLE XXIX.--PERFORMANCE ANALYSIS OF EXPERIMENT OPERATION

SUBTASK ELEMENT	DESCRIPTION	TIME SEC. † 1G	†† 0G	††† .1G	COMMENTS
UNSTOW ELECTRICAL UNIT.	OPENS CSU. REMOVES ELECTRICAL UNIT FROM COMPARTMENT A. CLOSES CSU. MANEUVERS INTO BEST POSITION TO INSTALL ELECTRICAL UNIT ON WASTE MANAGEMENT SYSTEM (WMS).	20	25	20	1G-SUBJECT APPEARS TO MOVE SLOWER THAN NORMAL DURING THIS SUBTASK. 0G-SUBJECT FLOATS FREE OF RESTRAINTS IN A PRONE POSITION ABOVE THE WMS FRAME.
INSTALL ELECTRICAL UNIT.	REMOVES TOOLS FROM FLIGHT SUIT AND INSTALLS ELECTRICAL UNIT ON WMS. CONNECTS WIRING. RESTOWS TOOLS IN FLIGHT SUIT.	325	305	270	1G-SUBJECT PLACES NUTS AND BOLTS FOR UNIT ON FLOOR AND RETRIEVES THEM AS HE NEEDS THEM TO INSTALL THE UNIT. HE INSTALLS UNIT WHILE IN A SQUATTING POSITION, KNEELING ON HIS LEFT KNEE. 0G-SUBJECT HOLDS HARDWARE IN HIS LEFT HAND WHILE INSTALLING ELECTRICAL UNIT. HE USES THE WMS FRAME AS A HANDHOLD WITH HIS LEFT HAND. ZERO GRAVITY DEFINITELY AIDS TASK EFFICIENCY HERE.
UNSTOW WMS SEAT.	MOVES TO CSU. OPENS CSU AND REMOVES WMS SEAT. CLOSES CSU AND MOVES INTO BEST POSITION TO INSTALL WMS SEAT.	20	20	10	
INSTALL WMS SEAT.	REMOVES TOOL FROM FLIGHT SUIT AND INSTALLS SEAT ON	60	160	65	1G-SUBJECT NOTES THAT BODY POSITION FOR SCREW INSTALLATION

† Reference FIG. 45, †† Reference FIG. 43, ††† Reference FIG. 44

TABLE XXIX.--PERFORMANCE ANALYSIS OF EXPERIMENT OPERATION - CONTINUED

SUBTASK ELEMENT	DESCRIPTION	TIME SEC.			COMMENTS
		1G	0G	.1G	
	WMS FRAME. TIGHTEN SEAT NUTS ON UNDERSIDE OF FRAME. RESTOW TOOL IN FLIGHT SUIT.				ON SEAT IS AWKWARD. 0G-SUBJECT NOTES THAT THE UP-SIDE DOWN POSITION USED DUR-ING THIS SEAT INSTALLATION IS VERY COMFORTABLE AND ALLOWS EASY INSTALLATION OF THE SEAT.
UNSTOW URINE STORAGE EVA-PORATOR.	MOVES TO CSU. OPENS COM-PARTMENT B AND REMOVES URINE STORAGE EVAPORATOR. CLOSES COMPARTMENT B. MOVES INTO BEST POSITION TO INSTALL EVAPORATOR ON WMS FRAME.	20	20	20	
INSTALL EVA-PORATOR ON WMS FRAME.	LINES UP SLIDE TRACKS AND INSERTS EVAPORATOR ON WMS FRAME. SLIDES EVAPORATOR BACK UNTIL UNIT STOPS AT BACK OF TRACK. MAKES ELECTRICAL CONNECTIONS TO EVAPORATOR.	45	35	35	1G-SUBJECT NOTES ONLY MINOR DIFFICULTY IN LINING UP EVA-PORATOR ON SLIDE TRACK.
UNSTOW FECAL RESIDUE STOR-AGE UNIT.	MOVES TO CSU. OPENS COM-PARTMENT C AND REMOVES FECAL RESIDUE STORAGE UNIT. CLOSES COMPARTMENT C. MOVES INTO BEST POSITION TO INSTALL STORAGE UNIT ON FRAME.	10	25	10	

TABLE XXIX.--PERFORMANCE ANALYSIS OF EXPERIMENT OPERATION - CONTINUED

SUBTASK ELEMENT	DESCRIPTION	TIME SEC.			COMMENTS
		1G	0G	.1G	
INSTALL FECAL RESIDUE STORAGE UNIT.	LINES UP SLIDE TRACKS OF STORAGE UNIT AND WMS FRAME AND INSERTS UNIT ON TRACK. SLIDES UNIT BACK UNTIL IT MATES WITH EVAPORATOR.	10	10	20	1G-SUBJECT NOTES NO DIFFICULTY IN LINING UP STORAGE UNIT ON SLIDE TRACK.
UNSTOW CANISTER RACK.	MOVES TO CSU. OPENS COMPARTMENT D AND REMOVES CANISTER RACK. CLOSES COMPARTMENT D. MOVES INTO BEST POSITION TO INSTALL CANISTER RACK ON WMS FRAME.	15	5	5	
INSTALL CANISTER RACK.	LINES UP SLIDE TRACKS OF CANISTER RACK AND WMS FRAME AND SLIDES UNIT INTO INSTALLED POSITION.	5	5	10	1G-NO LINE-UP PROBLEMS ENCOUNTERED.
UNSTOW HOSE VACUUM.	MOVES TO CSU. OPENS COMPARTMENT E AND REMOVES VACUUM HOSE. CLOSES COMPARTMENT E. MOVES INTO BEST POSITION TO INSTALL HOSE ON WMS.	5	10	5	0G-SUBJECT FORGETS TO INSTALL VACUUM HOSE.
INSTALL VACUUM HOSE.	INSERTS HOSE ON CANISTER RACK ADAPTER. CONNECTS OTHER END TO VACUUM LINE OUTLET.	10	--	5	CONNECTIONS ARE PRESS FIT COUPLINGS. 0G-SUBJECT NEGLECTS TO INSTALL VACUUM HOSE.

TABLE XXIX.--PERFORMANCE ANALYSIS OF EXPERIMENT OPERATION - CONTINUED

SUBTASK ELEMENT	DESCRIPTION	TIME SEC.			COMMENTS
		1G	0G	.1G	
UNSTOW CANISTER NO. 1.	MOVES TO CSU. OPENS COMPARTMENT F AND REMOVES CANISTER NO. 1. CLOSES COMPARTMENT F.	10	10	10	
INSTALL CANISTER NO. 1.	MOVES TO CANISTER STORAGE UNIT. OPENS UNIT A AND INSERTS CANISTER IN RECEPTACLE. CLOSES UNIT A.	10	15	10	
UNSTOW CANISTER NO. 2.	MOVES TO CSU. OPENS COMPARTMENT F AND REMOVES CANISTER NO. 2. CLOSES COMPARTMENT F.	5	10	10	
INSTALL CANISTER NO. 2.	MOVES TO CANISTER STORAGE UNIT. OPENS UNIT A AND INSERTS CANISTER IN RECEPTACLE. CLOSES UNIT A.	8	5	5	
UNSTOW CANISTER NO. 3.	MOVES TO CSU. OPENS COMPARTMENT F AND REMOVES CANISTER NO. 3. CLOSES COMPARTMENT F.	11	5	5	1G-SUBJECT PAUSES TO REPLACE A CANISTER LID BEFORE MOVING TO THE CANISTER STORAGE UNIT.
INSTALL CANISTER NO. 3.	MOVES TO CANISTER STORAGE UNIT. OPENS UNIT B AND INSERTS CANISTER IN RECEPTACLE. CLOSES UNIT B.	11	5	5	

TABLE XXIX.--PERFORMANCE ANALYSIS OF EXPERIMENT OPERATION - CONTINUED

SUBTASK ELEMENT	DESCRIPTION	TIME SEC.			COMMENTS
		1G	0G	.1G	
UNSTOW CANISTER NO. 4.	MOVES TO CSU. OPENS COMPARTMENT F AND REMOVES CANISTER NO. 4. CLOSES COMPARTMENT F.	11	5	10	1G-SUBJECT PAUSES TO REPLACE A CANISTER LID BEFORE MOVING TO THE CANISTER STORAGE UNIT.
INSTALL CANISTER NO. 4.	MOVES TO CANISTER STORAGE UNIT. OPENS UNIT B AND INSERTS CANISTER IN RECEPTACLE. CLOSES UNIT B.	12	10	5	
UNSTOW CANISTER NO. 5.	MOVES TO CSU. OPENS COMPARTMENT G AND REMOVES CANISTER NO. 5. CLOSES COMPARTMENT G. MOVES TO BEST POSITION TO INSTALL CANISTER NO. 5 ON WMS CANISTER RACK.	20	10	5	0G-SUBJECT IS IN STANDING POSITION AT THE CSU SIMILAR TO HIS POSITION IN 1G.
INSTALL CANISTER NO. 5.	INSERTS CANISTER NO. 5 THROUGH WMS SEAT AND ALIGNS WITH CANISTER RACK RECEPTACLE. PRESSES CANISTER FIRMLY ON RECEPTACLE. VERIFIES THAT CANISTER IS SECURE.	5	10	5	1G-SUBJECT NOTES THAT ALIGNMENT OF CANISTER ON RECEPTACLE IS NO PROBLEM.
UNSTOW CANISTER NO. 6.	MOVES TO CSU. OPENS COMPARTMENT G AND REMOVES CANISTER NO. 6. CLOSES COMPARTMENT G. MOVES TO BEST POSITION TO INSTALL ON WMS GAS MANIFOLD.	10	10	5	

TABLE XXIX.--PERFORMANCE ANALYSIS OF EXPERIMENT OPERATION - CONTINUED

SUBTASK ELEMENT	DESCRIPTION	TIME SEC. 1G	0G	.1G	COMMENTS
INSTALL CANISTER NO. 6.	INSERTS CANISTER NO. 6 ON WMS GAS MANIFOLD RACK RECEPTACLE. VERIFIES THAT CANISTER IS SECURE.	5	5	5	1G-SUBJECT NOTES THAT ALIGNMENT OF CANISTER ON MANIFOLD RACK RECEPTACLE IS NO PROBLEM
UNSTOW FREON HOSE.	MOVES TO CSU. OPENS COMPARTMENT H AND REMOVES FREON HOSE. CLOSES COMPARTMENT H. MOVES TO BEST POSITION TO INSTALL HOSE ON WMS RECEPTACLE.	15	5	10	1G-SUBJECT STOPS TO UNTANGLE HOSE.
INSTALL FREON HOSE.	ATTACHES FREON HOSE TO APPROPRIATE RECEPTACLES. UNSTOWS TOOL FROM FLIGHT SUIT AND TIGHTENS HOSE FITTINGS. RESTOWS TOOL IN FLIGHT SUIT.	40	75	30	SUBJECT TIGHTENS FREON HOSE FINGER TIGHT; HE NEGLECTS TO USE TOOL AT ALL THREE GRAVITY LEVELS.
UNSTOW URINE HOSE.	MOVES TO CSU. OPENS COMPARTMENT H AND REMOVES URINE HOSE. CLOSES COMPARTMENT H. MOVES TO BEST POSITION TO INSTALL URINE HOSE ON WMS RECEPTACLE.	12	10	10	
INSTALL URINE HOSE.	ATTACHES HOSE TO URINE OUTLET VALVE. INSERTS URINE RECEPTACLE ON WMS RECEPTACLE HOLDER.	20	15	20	URINE HOSE FITTING IS A PRESSURE FIT ONLY.

began with the subject inside the compartment, positioned in front of the stowage cabinet. He removed the electrical connector unit and several hand tools from the stowage cabinet, holding the cabinet door as a restraint aid, Figure 43a. The electrical unit was then transferred to the waste management subsystem (WMS). The subject used available handholds to aid in locomotion. He attached the electrical unit to the WMS frame, Figure 43b. The manipulation of bolts and small objects during this task required that he closely control his body position. The subject had no difficulty exercising this control by securing a handhold on the WMS frame.

He returned to the stowage cabinet using available handhold locomotion aids and removed the WMS seat. The seat was then attached to the WMS. The subject held the seat to the WMS frame with his left hand and inserted the bolts with his right hand, Figure 43c. He allowed his feet to drift upward until he was in an upside-down position with reference to the normal compartment orientation. From this position, he could tighten the bolts more comfortably. The subject moved to the stowage cabinet and removed the urine storage evaporator. The evaporator was to be mounted on a slide track on the WMS frame and connected to an electrical line. The subject encountered some difficulty when aligning the evaporator on the track. He held the evaporator with his left hand while holding the frame with his right, Figure 43d. After a momentary pause to align the evaporator, the installation was completed.

The subject moved to the stowage cabinet using available handholds as his locomotion aid. He unstowed the fecal residue storage unit from the cabinet. The available handholds were also used for restraint during unstowage. The subject pushed away from the cabinet and soared to the WMS. The residue storage unit was mounted on the same track as the urine evaporator, Figure 43e. No trouble was encountered in alignment and the storage unit was pushed onto the track until it came in contact with the urine evaporator. Stability was maintained by holding the WMS frame with his right hand.

The subject returned to the stowage cabinet and removed the canister rack. He moved to the WMS using available handholds as locomotion aids. The canister rack was mounted on a slide track beneath the seat, Figure 43f, and was slid into position with no difficulty, employing handholds as restraint aids, Figure 43g.

The subject next was required to remove a vacuum hose from the stowage cabinet and install it on the WMS, connecting one end to the canister rack and the other end to a vacuum outlet. The subject overlooked this portion of the task even though a procedure checklist had been provided. Instead, he immediately moved to the stowage cabinet and removed canister No. 1. He pushed away from the cabinet and soared to the opposite wall where he stowed the canister in the drying rack. He soared back to the stowage cabinet and

repeated this procedure with canisters No. 2, 3, and 4, individually. No differences were observed during the transfer of the canisters.

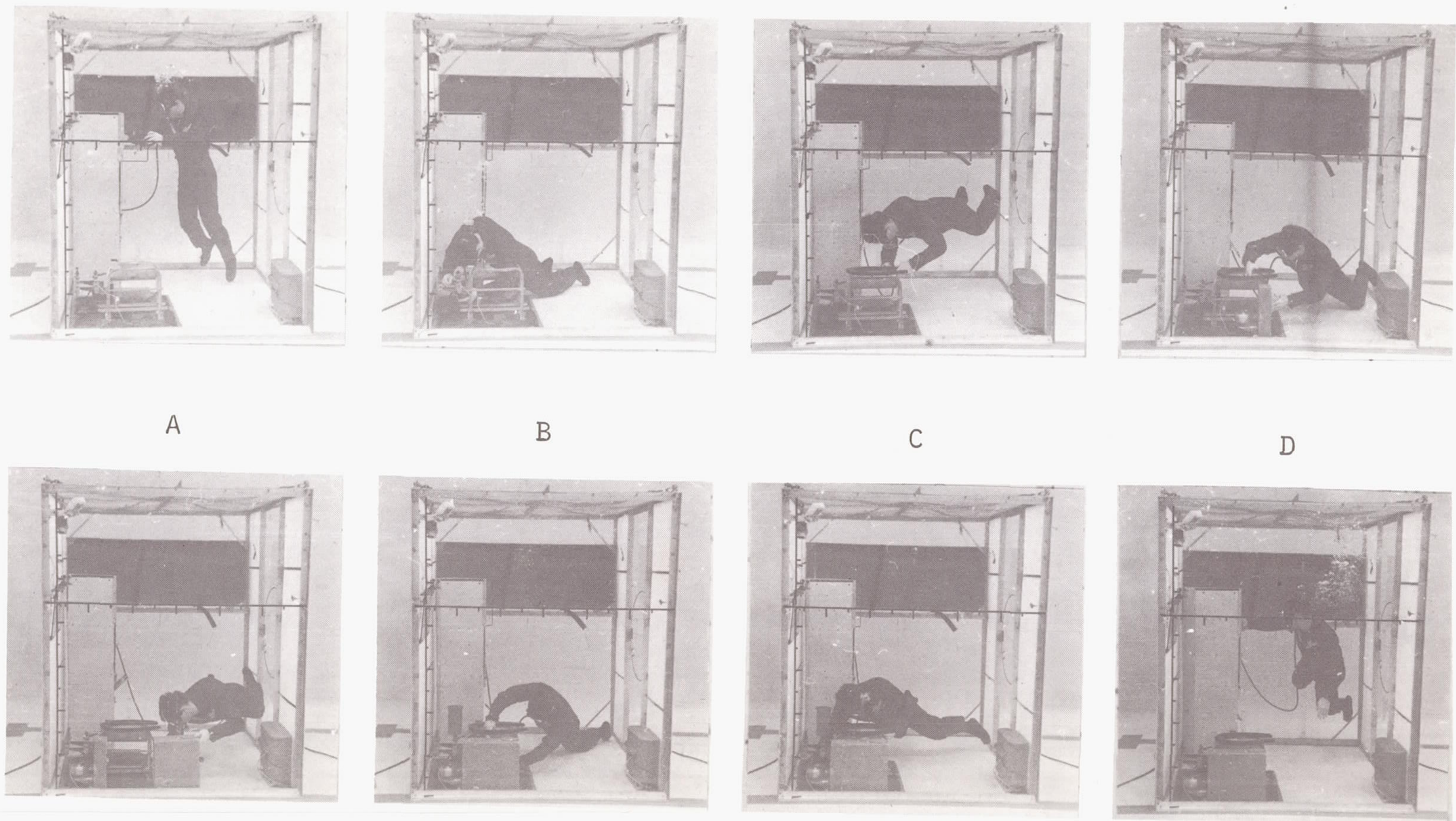
The subject returned to the stowage cabinet after placing canister No. 4 in the drying rack, Figure 43h. He unstowed canister No. 5 and transferred it to the WMS. Handholds were used as locomotion aids. He attached the canister to the canister rack while holding the WMS seat for restraint, Figure 43i. He next removed canister No. 6 from the stowage cabinet and transferred it to the WMS, Figure 43j. Canister No. 6 was installed on the gas manifold behind the seat.

The subject moved to the stowage cabinet and unstowed the freon hose which he carried to the WMS and attached it to the appropriate receptacle, Figure 43k. The subject maintained a handhold on the WMS for restraint The subject returned to the stowage compartment and removed the urine hose. The urine hose was transferred to the WMS. The receptacle end of the hose was placed in its holder on the front of the fecal residue storage unit. The other end was attached to the urine outlet valve on the rear of the WMS, Figure 43 1. This completed the Maintenance of Waste Management Subsystem task.

One-twelfth gravity - The subject entered the compartment hatch, stepping over the 26 inch bulkhead. No visible difference was noted between the one-twelfth and the one-sixth gravity entrance. This was mainly because the subject used the top and sides of the hatch to push himself down to the floor of the compartment, in a manner similar to pressure walking between surfaces. He moved immediately to the work table and unstowed the clipboard. His movement was a combination of walking and soaring.

He recorded the pressure gauge reading and then restowed the checklist in the CSU. The subject assumed the same basic kneeling position as in all the simulated reduced gravity runs. He did not use the structure as a handhold and it did not appear necessary to do so. The subject next disconnected the fluid and vacuum lines. He unlatched the unit from its base by deactivating the quick release bolt latches. He used the perimeter handrail to regain a standing position. He lifted the WMS and began to turn toward the work table. He released his handhold on the perimeter handrail and used both hands to place the unit in its checkout position. He performed the checkout and capacitor installation. He noted that he could utilize leg friction against the front bulkhead to hold his body in the lean-back attitude without the use of other handholds.

The subject returned the structure to its base position after installing the electrical connector. He noted that there was no problem in handling units of this size, weight, or configuration, but suggested that handholds or handrails be made available when movement over distances of more than four or five feet was required.



A B C D

E F G H

FIGURE 43 - MAINTENANCE TASK SEQUENCE (ZERO GRAVITY)

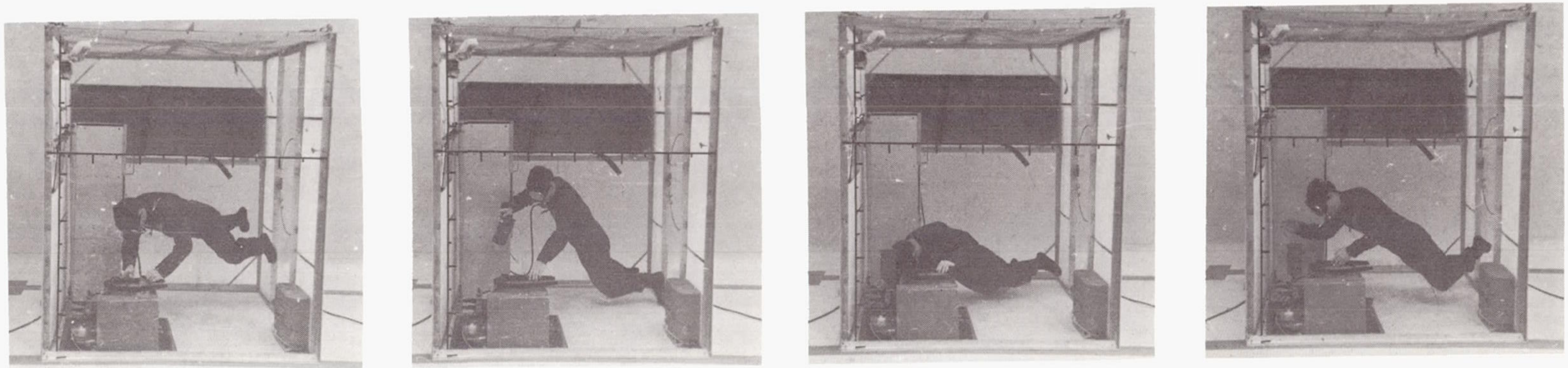


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FIGURE 43 - MAINTENANCE TASK SEQUENCE (ZERO GRAVITY - CONTINUED)

The subject reattached the fluid vacuum lines to the unit and tightened all connections. He maintained a stationary position throughout this maneuver. The subject moved to the drying rack and unstowed the canisters, installing them on the WMS. He noted that the installations at the WMS were all easily accomplished in the standing position. He completed the installation of the seat and exited the compartment using the structure to pressure walk through and out of the hatch. The task ended when the subject closed the hatch.

One-tenth gravity - A one-tenth gravity simulation run was conducted to compare the effects of simulated gravity on task performance. This run started with the subject positioned in front of the stowage cabinet, as in the zero gravity run. He opened the cabinet and removed the electrical panel and several hand tools, Figure 44a. The subject stood on the floor requiring no restraint aids when unstowing the equipment, due to the low but effective gravity level. The subject assumed a kneeling position next to the WMS and then proceeded to attach the electrical panel, Figure 44b. He did not require any restraint aids to maintain body position.

The subject moved back to the stowage cabinet on his knees and withdrew the WMS seat. He transferred the seat to the WMS and proceeded to bolt it into position. He found it necessary to assume a prone position when tightening the bolts under the seat, Figure 44c. He moved back to the stowage cabinet and removed the urine storage evaporator. The evaporator was then transferred to the WMS. No locomotion aids were used for movement as the subject was perfectly capable of walking inside the mock-up. The urine storage evaporator was then positioned on its slide track on the side of the WMS, Figure 44d. The electrical connection was made and the evaporator was slid into position.

The subject returned to the stowage cabinet and removed the fecal residue storage unit. He required no restraints or locomotion aids during this time. He returned to the WMS, still on his knees, and inserted the storage unit on the slide track with the urine evaporator, Figure 44e. The slight gravity level appeared to aid in the manipulation and operation with the small parts.

The canister rack was next unstowed from the cabinet, Figure 44f, and placed on its slide track beneath the seat. The subject maintained his balance by supporting himself by holding onto the WMS seat when inserting the canister rack.

The subject removed the vacuum hose from the stowage cabinet and carried it to the WMS. He connected one end of the hose to the canister rack and the other end to a vacuum line. He needed both hands to make the connection effectively, but, since he had effective weight, this motion posed no problem.

The subject returned to the stowage cabinet and regained his standing position to unstow canister No. 1. He unstowed the canister and moved to the opposite wall where he inserted it into the drying rack, Figures 44f and 44g. No locomotion aid was needed when moving between the stowage cabinet and the drying rack as the subject simply walked where he wished without any apparent difficulty. He then repeated this procedure for canisters No. 2, 3, and 4. Canister No. 5 was unstowed from the cabinet and transferred to the WMS where it was positioned on the canister rack, Figure 44i. Canister No. 6 was unstowed from the cabinet and placed on the vacuum manifold behind the seat, Figure 44j.

The subject returned to his kneeling position and unstowed the freon hose from the stowage cabinet. Using both hands, he attached the hose to its appropriate fittings on the WMS, Figure 44k. He next unstowed the urine hose and transferred it to the WMS, Figure 44 l. One end was attached to its bracket on the front of the WMS and the other end to the urine outlet valve in the rear. After this, the subject assumed a standing position at which point the test was concluded.

One-sixth gravity - The subject entered the hatch by stepping through the opening and making contact with the compartment floor. He moved to the work table area by using handholds to expedite body positioning. He unstowed the checklist from the CSU and moved to the WMS unit opposite the work table area, adjacent to the hatch. At the WMS position, he performed an instrument check and recorded the pressure reading on the checklist. He assumed a kneeling position for this task and, after completing the writing, he used handholds on the WMS to regain a standing position. He turned approximately 180 degrees and restowed the checklist.

The gauge reading indicated a WMS malfunction. The procedure was to isolate and repair this malfunction. Assuming the same basic kneeling position as before, the subject disconnected the WMS, unlatching the unit from the floor. The one-sixth gravity appeared to aid the subject in this maneuver, giving him the necessary stability to exert the force required. This did not detract from his ability to maneuver.

The subject used the perimeter handrail to regain his standing position. He noted no trouble in lifting the structure with one hand at one-sixth gravity. He released the handhold and placed the WMS on the work table. The subject noted that the handhold was not necessary after regaining his standing position. The reduced weight of the WMS made maneuvering extremely easy. At the work table, the subject began a systematic checkout of the WMS unit. He unstowed the tools from the CSU and replaced a defective capacitor and electrical connector. The subject performed this entire maneuver standing in one position in front of the work table. When making the

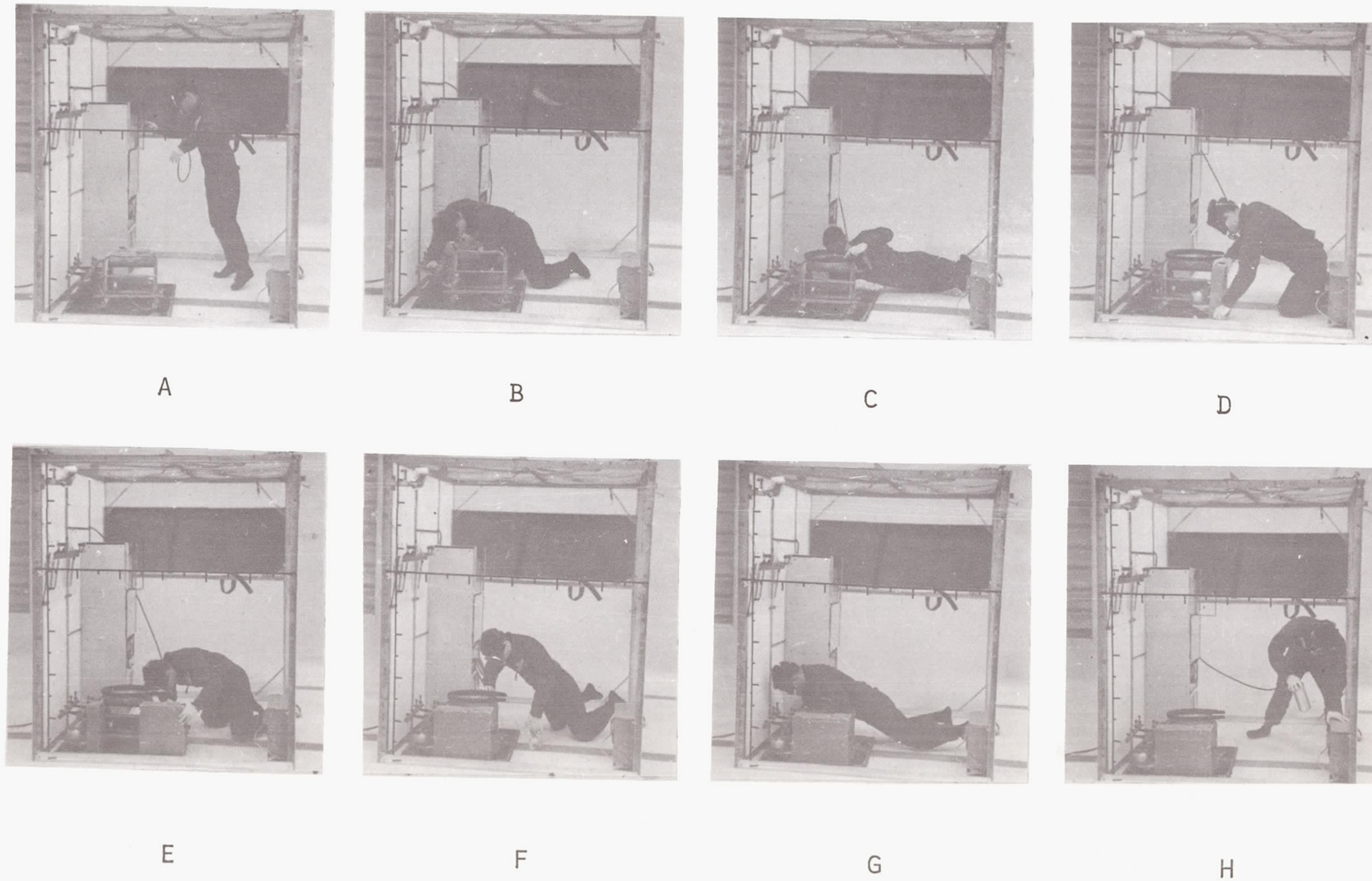

FIGURE 44 - MAINTENANCE TASK SEQUENCE (0.1 GRAVITY)

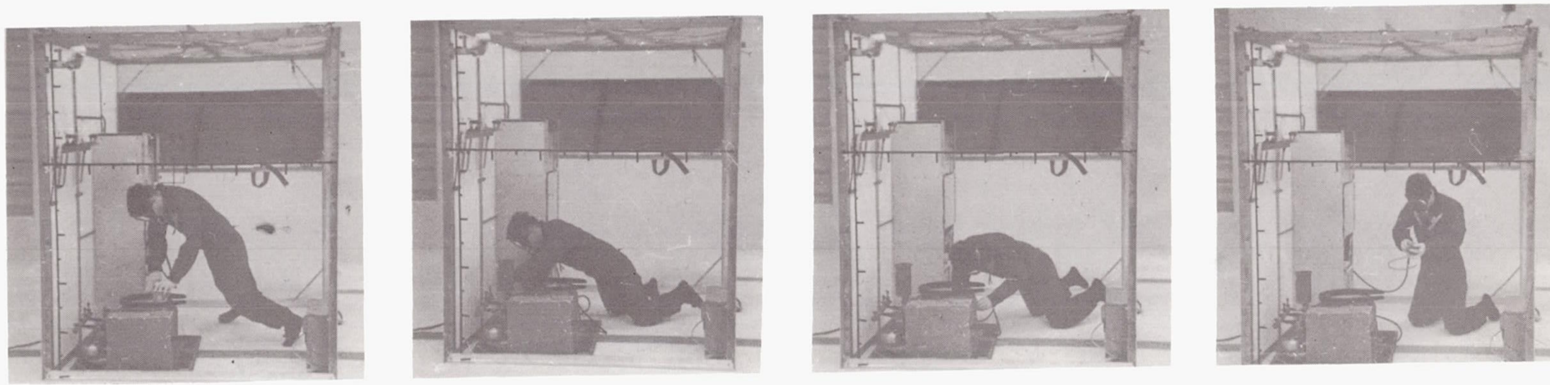

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FIGURE 44 - MAINTENANCE TASK SEQUENCE (0.1 GRAVITY - CONTINUED)

final adjustments on the electrical board, he assumed a semi-kneeling attitude and used handholds on the work table and the WMS structure to maintain his position. He noted that this was the most difficult body position encountered at this gravity level. In this position he was required to lean back and his simulated weight required a handhold for body stability.

The subject next moved the WMS back to its base position. He used no handholds to aid this maneuver and later noted that they were not necessary. After reconnecting the vacuum and fluid lines, the subject attached the newly installed electrical connector to the wall receptacle. This connection required both hands and the subject leaned against the WMS structure to maintain his position. He used the available structure again to regain his standing position.

The subject's next set of maneuvers was a combination of equipment transfer and installation on the WMS. He next unstowed the canister adapter and inserted the adapter into its slide track. The subject did not use handholds for these maneuvers and changed from a standing walking position to a kneeling installation position freely. He noted no difficulty in handling either the large storage unit or the small canister adapter.

The subject moved to the drying rack and unstowed the receptacle canister. He used the perimeter handrail to expedite body positioning. He repeated this maneuver, installing two canisters, noting that the handrail was not an absolute necessity, but was an advantage. His final task was to install the liquid receptacle and the seat. He noted no difficulty in unstowing or transferring these units. He performed the seat installation after attaching the receptacle hose and noted that the one-sixth gravity level aided in the installation, particularly in bolt tightening. At the completion of this installation the subject exited the hatch.

One gravity control run - A film sequence comparable with the above descriptions is given for the one G control run, Figure 45.

<u>Geometry, size, and space limitation of Maintenance of Waste Management Subsystem task</u>.--Since the research performed has shown significant effects of compartment space limitations on human operation of equipment in simulated weightless conditions, it followed that the compartment configuration would also affect the maintenance of this equipment. The following Maintenance task was designed to analyze these effects and also to obtain an indication of the effect of gravity on compartment geometry, size, and space requirements.

The waste management subsystem was chosen for this task analysis because it represented future design flight hardware and because it

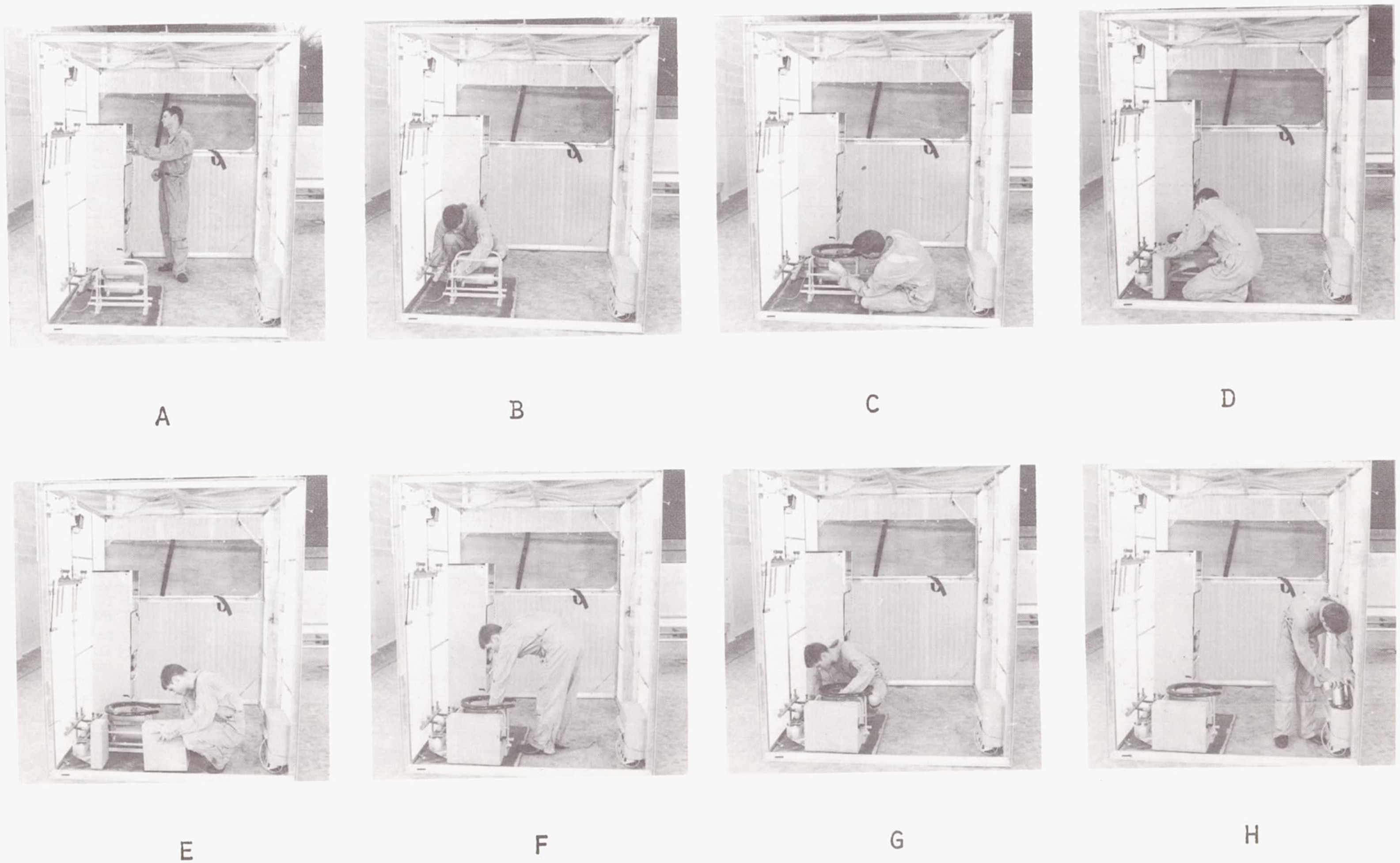

FIGURE 45 - MAINTENANCE TASK SEQUENCE (ONE GRAVITY)

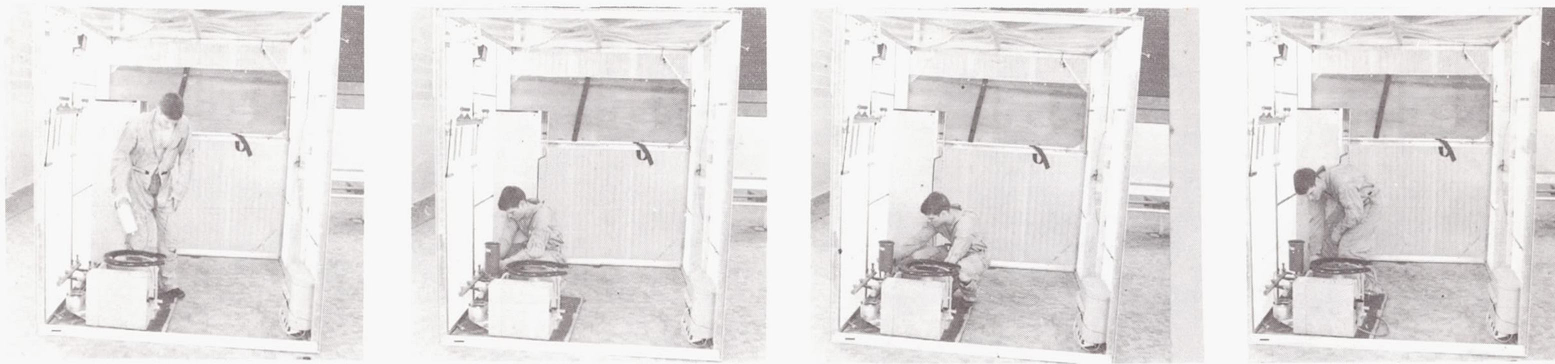

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FIGURE 45 - MAINTENANCE TASK SEQUENCE (ONE GRAVITY)-CONTINUED

afforded a variety of maintenance operations. The unit was separated into two individual stations. Figure 46 is a plan view showing the position of these stations in the standard 84" x 84" x 72" mock-up configuration.

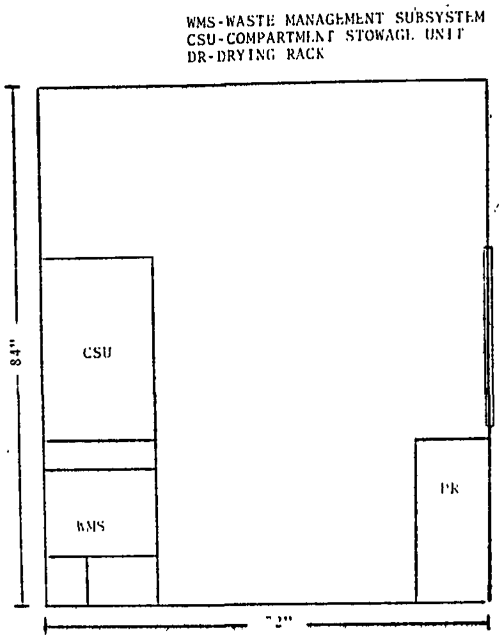


FIGURE 46 - PLAN VIEW OF EQUIPMENT FOR MAINTENANCE TASK

The mock-up configuration included a primary waste control system adjacent to the compartment stowage unit and opposite the waste management storage system. The placement of these units was intended to provide the means to investigate operations requiring movement as well as maintenance operations in a fixed position. Subject-equipment interaction was considered only a secondary parameter since this problem had been investigated in the previous tasks.

Measurements of the maximum required space envelop and compartment volumes for the various subtasks comprising the Maintenance task were made to determine practical compartment size and space limitations. Table XXX presents the results of these measurements for the two primary positions where the Maintenance task occurred and the three gravity levels analyzed. A comparison of the effects of the various gravity levels on the comparison of the spatial envelop and geometry is given in Figure 47. The comparison shows a significant difference between the results of the one gravity run and the results from the two reduced gravity simulation runs. The zero and one-tenth gravity levels required significantly more space

TABLE XXX

MAXIMUM SPACE ENVELOP AND VOLUME REQUIRED FOR THE MAJOR MAINTENANCE TASK MANEUVERS

		GROSS MAINTENANCE	PRECISION MAINTENANCE	MODULE STORAGE
ZERO GRAVITY	x	5.8	5.2	5.0
	y	5.8	2.9	5.0
	z	5.5	5.2	5.9
	VOL.	218.4	78.3	147.5
1/12 GRAVITY	x	5.8	3.9	4.7
	y	4.4	5.9	4.0
	z	5.9	2.5	5.3
	VOL.	150.6	57.5	99.6
1/10 GRAVITY	x	5.9	5.2	3.5
	y	4.5	2.8	3.5
	z	5.9	5.2	4.5
	VOL.	191.4	75.6	55.1
1/6 GRAVITY	x	5.9	3.6	4.0
	y	4.8	5.9	5.8
	z	5.9	2.1	3.5
	VOL.	167.0	44.6	81.2
ONE GRAVITY (CONTROL)	x	4.7	2.5	2.5
	y	3.5	3.0	3.9
	z	2.5	3.0	2.5
	VOL.	57.4	23.5	24.2

MEASUREMENTS IN FEET AND CUBIC FEET

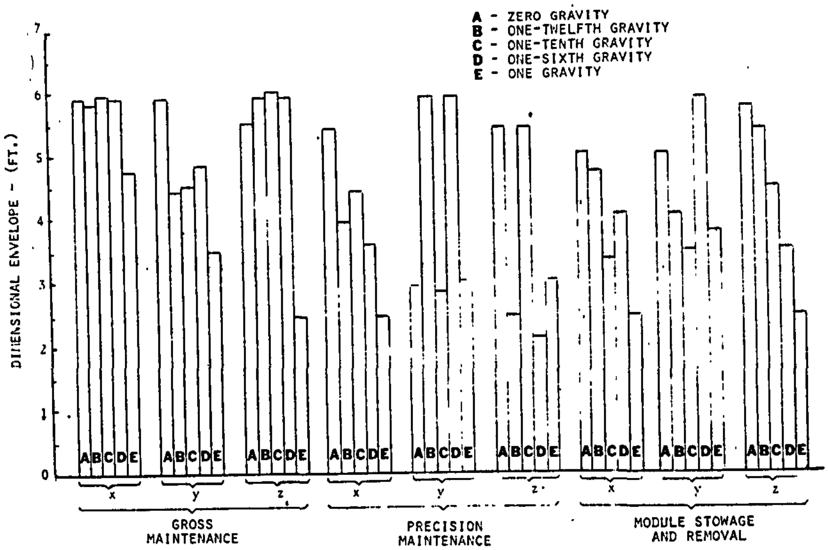


FIGURE 47 - THE EFFECT OF GRAVITY LEVEL ON PERFORMANCE OF THE MAINTENANCE TASK

than the one gravity performance, for all conditions analyzed. Of course, it should be noted that the space was available and previous task analysis has shown that reduced and zero gravities tend to fully utilize whatever space is made available. It is suggested that, if the compartment dimensions were smaller, the task could have been performed in a smaller envelop for both the simulated reduced gravity levels. Past task analysis and simulation at ERA have indicated that a decrease in space allotment may even increase the task efficiency.

Movement between the waste management units was performed easily at all gravity levels. In zero gravity, a combination soaring and handhold locomotion system was used. In the one-tenth G and one G, the subject simply walked from one position to the other, as required. The compartment size and equipment spacing did not decrease movement efficiency even though the distance between equipment units was greater than in any of the previous task simulations.

When performing the maintenance maneuvers at the one-sixth gravity level, the subject appeared to be able to maintain a stationary position on the compartment floor without the use of handrails or other restraint aids. His movement from one position to another was also accomplished without locomotion aids.

The subject noted, however, that performing the electrical repairs on the WMS was awkward. He compared his positioning for this maneuver to that of the one gravity position. The problem appeared to be that, as in the one gravity mode, the subject could not lean back in the proper position to work comfortably. In the one-tenth and one-twelfth gravity level modes, the subject maintained this psoition by applying sideways force with his legs against the CSU and the compartment bulkhead. Apparently the subject's added weight at one-sixth gravity was too large a force to overcome by the small frictional forces being applied with the subject's legs.

The subject did not use the soaring maneuver at the one-sixth gravity level. His movement from the work table to the drying rack station was limited to small steps.

It appeared that at the one-twelfth gravity level the subject reached his optimum gravity working mode. His positioning maneuvers are performed by a combination of soaring and walking. In order to maintain a stationary position he used the handholds, but he noted that they were not completely necessary. The one-twelfth gravity level allowed the subject to assume and maintain many positions that could not be reached at the higher gravity levels. The best example of this was the electrical unit repair at the work table. Using his legs to hold his position, the subject made the necessary repairs while in a semi-reclining position. He was, in effect, working under an overhanging equipment unit without the aid of restraints. Although this same maneuver could have been performed at the zero gravity level, the subject had the added weight advantage to aid in other positioning maneuvers.

In this task, as in all previous tasks, the subject did not use the entire height of the 7 foot compartment. In a reevaluation run of the Maintenance of the Waste Management Subsystem, the ceiling height was lowered to 6 ft 6 in. This variation did not affect task performance or efficiency but it appeared to be a more realistic compartment height. The subject attempted pressure walking between surfaces during this run at zero gravity and found it to be quite feasible but not especially useful as a locomotion aid for the Maintenance task maneuvers.

Conclusions.--The handholds proved a very efficient restraint aid for the zero gravity maintenance maneuvers. In this task, defined handholds were not placed at specific positions. The waste management subsystem equipment structure was such that solid handholds could be obtained by grasping any number of areas on the equipment. Two specific handholds were available on the folding work table. These proved especially useful in the Maintenance reevaluation task when portions of the waste management subsystem were removed from their structure positions and located on the work table for Maintenance operations. These handholds aided in both the manipulation

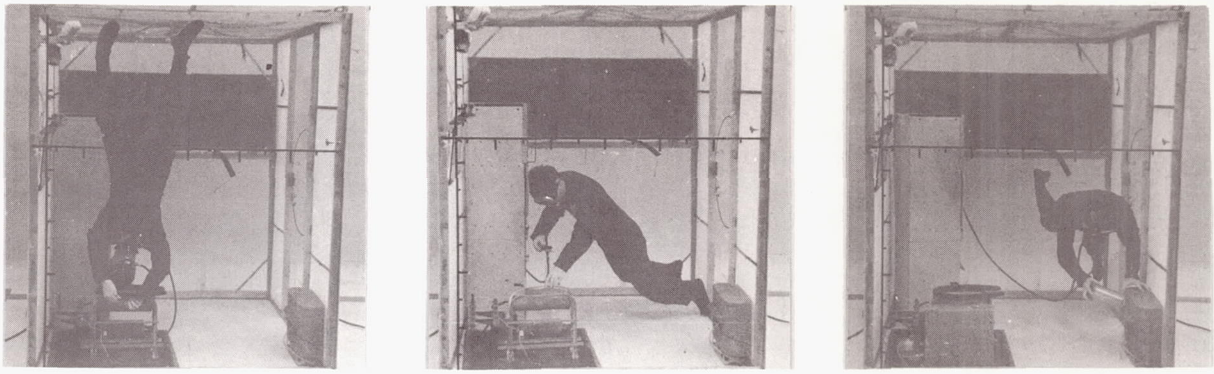
of the equipment from position to position and in stabilizing the subject's position while he performed the Maintenance maneuvers at the work table.

Restraints were not as necessary during the one-tenth gravity Maintenance operations. However, the handholds did prove a definite advantage as locomotion aids for this task. It was noticed, especially during the transfer of the waste management subsystem parts to the work table for repair, that the handholds afforded the extra support needed to attain fast and accurate positioning and to maintain balance.

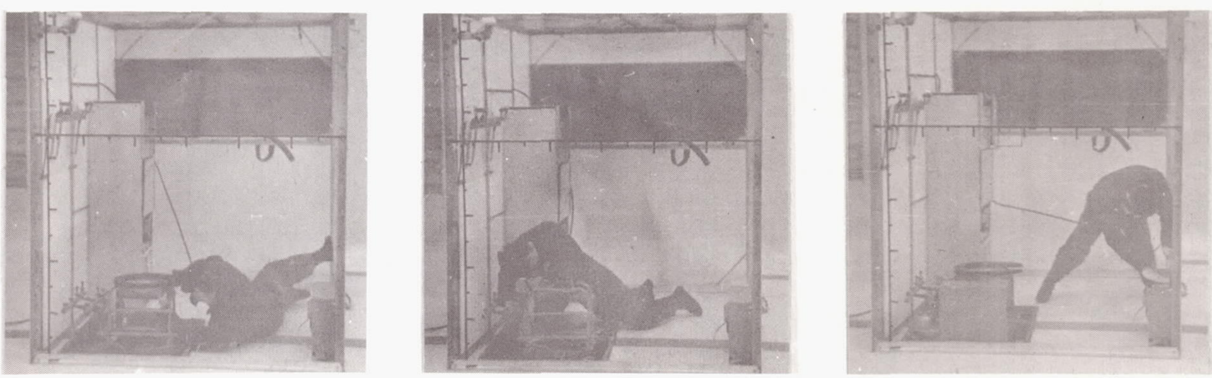
The most useful locomotion aid for the zero gravity run proved to be the handhold-soaring combination. The compartment size and configuration was such that movement from one equipment unit to another was almost within a handhold-to-handhold reaching mode. A minimum amount of free soaring was necessary and, as in previous tasks, proved extremely efficient. Initial evaluations showed that a number of the restraints and locomotion aids were applicable to the Maintenance task. However, compared to the handhold restraints and handhold-soaring locomotion combination, all other aids required more timely preparation in activation and deactivation. The most useful restraints other than the handholds were the waist tethers. Both the single and the two waist tethers restraints were found to be very helpful at the work table in the final reevaluation Maintenance task where equipment repairs were being made at the work table. The waist tethers allowed the subject to lean back away from the table in both the zero and one-tenth gravity modes. This position appeared to be ideal for certain portions of the repair operations, especially when performing precision adjustments on the underside of equipment.

Possibly the most significant result of the Maintenance task simulation was the effect of gravity level on the subject's working positions for a particular task maneuver, and thus the effect on the spatial envelop required for the task maneuver. Figure 48 is a pictorial comparison showing the subject's position for task maneuvers at the primary work area of the Maintenance task for the three gravity levels investigated. The first comparison shows a distinct variation in positioning preference between the three gravity levels. The subject is performing an installation task at the waste management subsystem. In the zero gravity mode, the subject drifted above the waste management subsystem maintaining his position by holding onto the subsystem structure with one hand. In this attitude, the subject could alter his position to reach his Maintenance task for the most efficient manipulation of the task maneuvers. He noted that of the three gravity levels this mode afforded the most efficient operation.

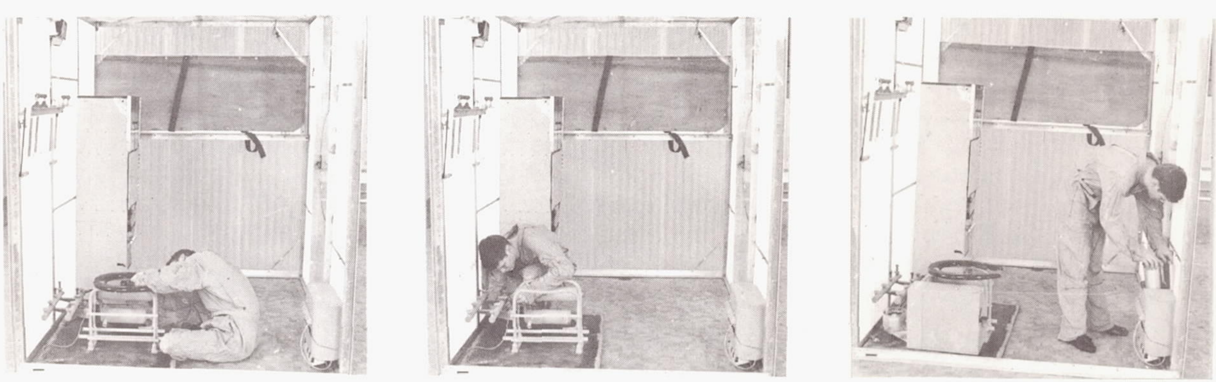
The subject performed the same task in the one gravity mode by assuming a squatting position at the waste management subsystem.



0 GRAVITY



0.1 GRAVITY



1 GRAVITY

WMS SEAT INSTALLATION — ELECTRICAL PANEL MAINTENANCE — DRYING RACK INSTALLATION

FIGURE 48 - COMPARISON OF THE EFFECT OF SIMULATED GRAVITY LEVEL ON BODY POSITIONS DURING THREE REPRESENTATIVE MAINTENANCE SUBTASKS

This appears to be a natural position, one that would be expected to perform this type of installation. It was noticed from this one gravity run that the installation was an awkward task to perform. The task became simplified when gravity was reduced and extremely easy when gravity was removed. The only sacrifice for simplifying the maneuver due to reduced gravity was the increase in the spatial envelop required to assume the most efficient task performance attitude in the zero gravity mode.

In the second comparison, the positioning variation is only apparent for the one gravity mode. The zero and one-tenth gravity mode positions show no visible attitude variations. The subject is performing a precision maintenance assembly at the waste management subsystem position. The difference between the one gravity and the zero and one-tenth gravity runs is a small but effective positioning preference.

The precision Maintenance assembly task requires close contact to the assembly area. In the one gravity mode, this contact is attained by squatting near the subsystem structure in a position similar to that of the previously discussed gross maintenance installation. Closer positioning to the work area would be desirable, but could not be attained without assuming an inclined or semi-prone position. The position would be awkward, if not impossible, to attain in the one gravity mode, but, as can be seen in the comparison sequence, the inclined prone position is easily attained in both the zero and one-tenth gravity modes. Film analysis of the task substantiated the fact that in the reduced and zero gravity mode this preferential positioning increased task efficiency.

Not all Maintenance maneuvers were affected by the gravity level. The third comparison shows the subject stowing canisters in the drying rack and fecal water recovery system. The stowage maneuver follows removal of the canisters from the CSU and movement to the drying rack station. The subject's attitude at each of the gravity levels appears the same throughout the entire maneuver of removal, movement, and stowage. The example shows the subject just after completing a soaring maneuver from the CSU to the drying unit. His position at the drying unit, when stowing the canister, was, in effect, dictated by the soaring maneuver.

All maneuvers of the Maintenance task could be performed at one gravity, zero gravity, and the reduced gravity levels. Comparison of the task times indicates that the one-tenth gravity reduced gravity task mode was the most efficient. This supports data from other related simulations indicating that reduced gravity around one-tenth gravity to be optimum from a human factors operational performance standpoint. Past experience has shown that there are both advantages and disadvantages to zero gravity operation; the advantage of mobility being counteracted by the disadvantage of

decreased ability to produce traction. One gravity operation also presents advantages and disadvantages opposing those of zero gravity. The ability to produce traction due to the availability of net weight is countered by the inherent decreased mobility since free-soaring is impossible. It follows then, that a level between one gravity and zero gravity could afford the optimum gravity level from a human factors operational basis. Previous simulation research programs performed for NASA-LRC by ERA indicates that the optimum is nearer the zero gravity level. It has also been noted that at simulated gravity levels, very near zero gravity, the apparent advantages of performance at reduced gravity levels completely disappear.

Combined effects of simulated gravity level and compartment size and geometry were demonstrated by the varying performance of the Maintenance task at the individual subtask level. Certain of the subtasks were directly constrained by the simulated gravity level, while there were no apparent differences between the performance of others at any of the gravity levels investigated. These results suggest that the valid task analysis of potential in-space tasks should be approached on an individual subtask basis and that the assumption that a particular maneuver or set of maneuvers is feasible at all gravity levels or in all compartment configurations cannot be deduced from the observation of the performance of the task at one simulated gravity condition. Indeed, these kinds of assumptions are oftimes invalid and lead to erroneous extrapolation of performance characteristics and equipment and procedures design criteria.

GENERAL CONCLUSIONS AND RECOMMENDATIONS

The present research effort has addressed the simulation of a variety of tasks consistent with manned operation in weightless and low gravity space stations. The tasks investigated included general living and housekeeping functions, personal hygiene and conditioning, space suit and general flight suit donning, operation and maintenance of representative hardware, data collection and manual processing, and cargo handling and stowage. All of the tasks addressed proved amenable to simulation by water immersion, for 0G and for 0.08G, 0.1G, and 0.16G level.

The primary emphasis during the program was to assess the effect of hardware placement, compartment geometry, and restraint and locomotion aids on human performance. To assess these factors, representative tasks were developed, averaging approximately 10 minutes in length, and the various combinations and versions of the restraints and locomotion aids were evaluated.

The basic compartment chosen for the simulation was a rectangular element, 84" x 84" x 72", in which the various equipment was placed. The subject could perform all of the required tasks in the space allotted. However, certain of the critical elements of the tasks showed that the location of equipment near walls or bulkheads caused varying degrees of significant access problems, both visual and manual.

The 32 inch diameter hatch proved to be adequate for the performance of all tasks assigned. Slight interactions were observed when the subject was transporting the cargo cylinders in the underarm mode.

The restraints evaluated during the research effort included: chair-seat belt, velcro sandals, fixed handholds, peripheral handrails, portable handrails, fixed foot restraints of the Gemini type, and toe traps. All of the restraints were evaluated against all of the tasks. With few exceptions, all restraints provided at least a measure of acceptable performance. Certain aspects of tasks involving gross subject motion benefited little from such fixed restraints as the chair-seat belt and the Gemini type foot device. The compartment size and configuration provided multiple and, to a large extent, universally distributed handholds which proved adequate and, at times, optimum for performance.

In general, handholds both specifically designed and naturally occurring should be used wherever possible since they act as combination locomotion aids and restraints, and there is no task efficiency loss due to restraint erection procedures. The subsequent addition of a peripheral handrail in the mock-up proved a singularly effective restraint concept. Specific handholds on cargo do not appear necessary unless the cargo size is greater than that considered under the present research.

Velcro is an exceptionally good restraint for attaching small hardware and containers to work tables, but does not provide the necessary restraint to counteract body forces produced by the subject, both in fixed location work and in movement. Waist tethers were the most effective restraint aids for the exercise tasks since they provided a compromise between freedom of motion and overall body fixity.

The locomotion aids evaluated during the program included: soaring, handhold-soaring, peripheral and erectable handrails, pressure walking between surfaces, and velcro sandals. Each of these locomotion aids was evaluated during each task simulation. With the exception of pressure walking between surfaces, all of the locomotion techniques proved adequate for the performance of the tasks.

Soaring and combination handhold-soaring proved to be the most effective locomotion aid, especially over the short to medium distances

accruing to work inside the compartment. The center erectable handrail proved to be the most effective locomotion aid for the Cargo Transfer task. This is chiefly due to the fixed path implicit in the Cargo Transfer task and due to the need of the subject to supply counter-torque in order to maintain a preferred body attitude during the cargo transport.

The overall compartment dimension proved to be more than adequate for the performance of all functions of the General and Housekeeping task except for the exercise subtask, where the full compartment volume was used. A dressing mirror proved very helpful in the don-doff subtask. The don-doff subtask was performed more efficiently in the reduced compartment size due to beneficial subject-compartment interactions.

Equipment Operation and Maintenance tasks are feasible in all gravity levels investigated within the confines of the reference compartment. For the most part, the tasks can be performed with minimum restraint and locomotion aids. Long duration operations at data and work consoles necessitate the use of a chair-seat belt system. However, optimum space allocation dictates that this chair-seat belt should be adjustable and capable of being stowed when not in use, to minimize interference with the subject.

Precision Maintenance tasks are easily performed at standing work stations, particularly when the stations are provided with the toe trap type foot restraints. These work stations also benefit from laterally located handholds on the work station. It was found that the work station should be liberally provided with velcro attachment pads for retention of tools and other small parts. No difficulty was found in manually taking and recording data at the various work stations. It proved to be very difficult to provide photographic data recording by the subject due to the limited space afforded by the compartment. Particular attention must be paid to provide adequate design of this necessary element of the data collection system.

Water immersion simulation has proved to be a very useful tool in evaluating manned intravehicular activites. It is recommended that the effort initiated with this contract, regarding the evaluation and comparison of the performance of subjects at various levels of simulated gravity, be continued and amplified to assess optimum space station gravity level from a human factors operation standpoint to aid vehicle designers in necessary system performance comparison.

The results of the Maintenance task evaluation, wherein representative pieces of space hardware were investigated, show that greater effort in evaluating operational performance of actual design hardware is warranted. This is particularly applicable to critical tasks of maintenance and repair.

It has also been shown that realistic evaluation of compartment configurations and hardware placement can be done by the water immersion simulation technique. During the present research, a technique has been discussed to eliminate the necessity for a face mask when working underwater. This method comprises the use of full contact lenses, still in the development stage. It is recommended that serious consideration be given to developing and validating this concept for use with future research programs to eliminate the artificial seeing conditions afforded by use of conventional face masks.

The results of the gravity level comparisons of similar task performance has shown that an optimum gravity level of approximately 0.1-0.2G exists from an overall human manual and motion performance basis. No effort has been made to ascertain consistent measures of human physiologic optima necessary to more fully utilize the data derived here. Future effort should be expended in cross-correlating "external" human factors performance with consistent biophysical measures during simulated task performance.

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GLOSSARY

IVA - intravehicular activity

EVA - extravehicular activity

MORL - manned orbital research laboratory

ORL - orbital research laboratory

AES - Apollo experiment systems

GEP - Gemini experiment package

MOT - manned orbital telescope

MOL - manned orbital laboratory

ERA - Environmental Research Associates

ALM - Apollo air lock module

SCUBA - self-contained underwater breathing apparatus

HOOKAH - breathing apparatus connected to surface by umbilical

CWG - constant wear garment

FPS - full pressure suit

WRS - weightless restraint sandals

PFU - personnel food unit

CSU - compartment storage unit

B/W - black and white movie film

G/NCP - guidance and navigation control panel

EMC - equipment module cabinet

WMS - waste management subsystem

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